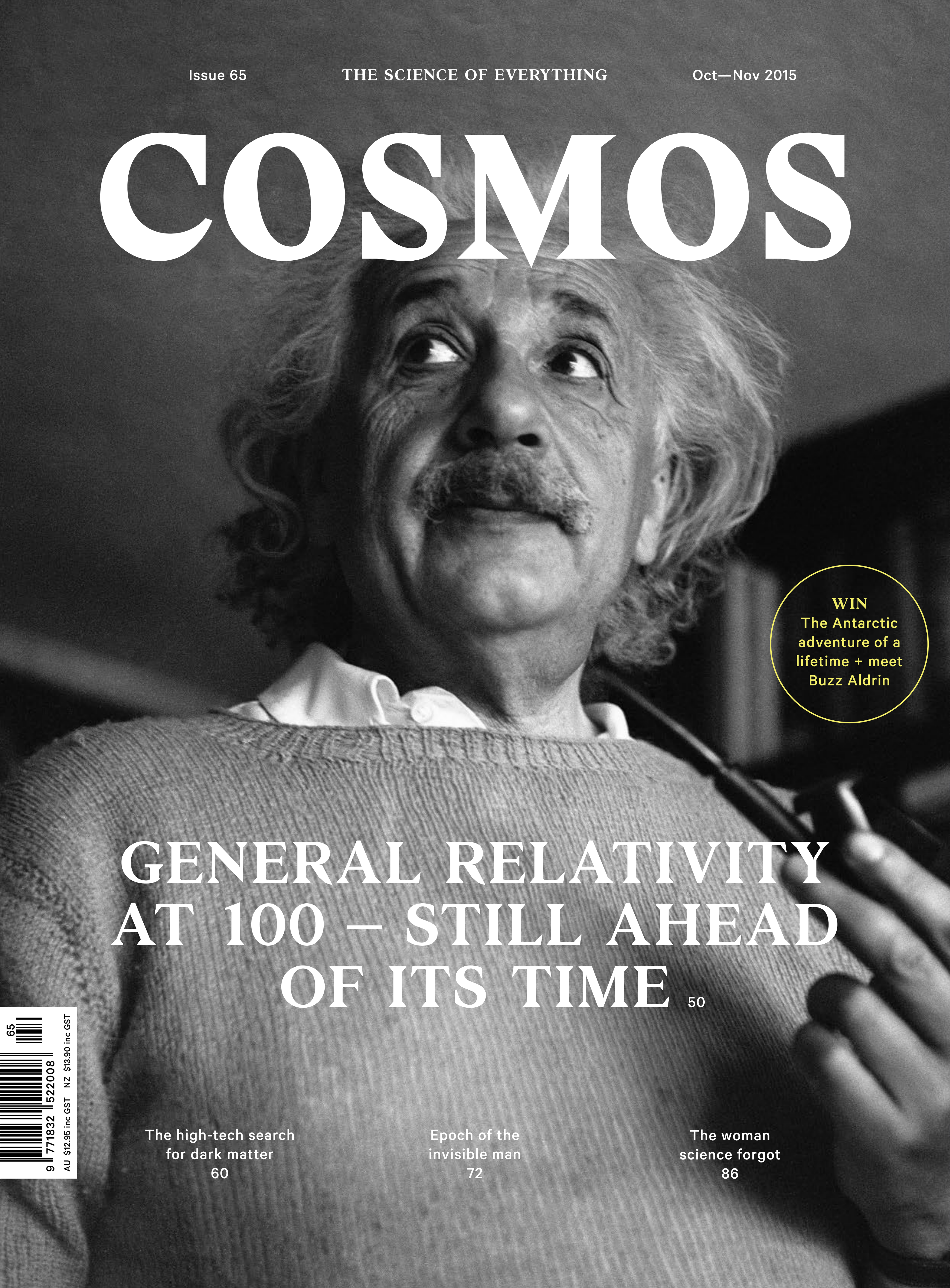
Issue 65 THE SCIENCE OF EVERYTHING Oct—Nov 2015

COSMOS



WIN
The Antarctic adventure of a lifetime + meet Buzz Aldrin

GENERAL RELATIVITY AT 100 – STILL AHEAD OF ITS TIME 50

AU $12.95 inc GST NZ $13.90 inc GST

ENGINEERING COURSES IN SYNC WITH INDUSTRY

THAT'S HOW UNIVERSITY SHOULD BE

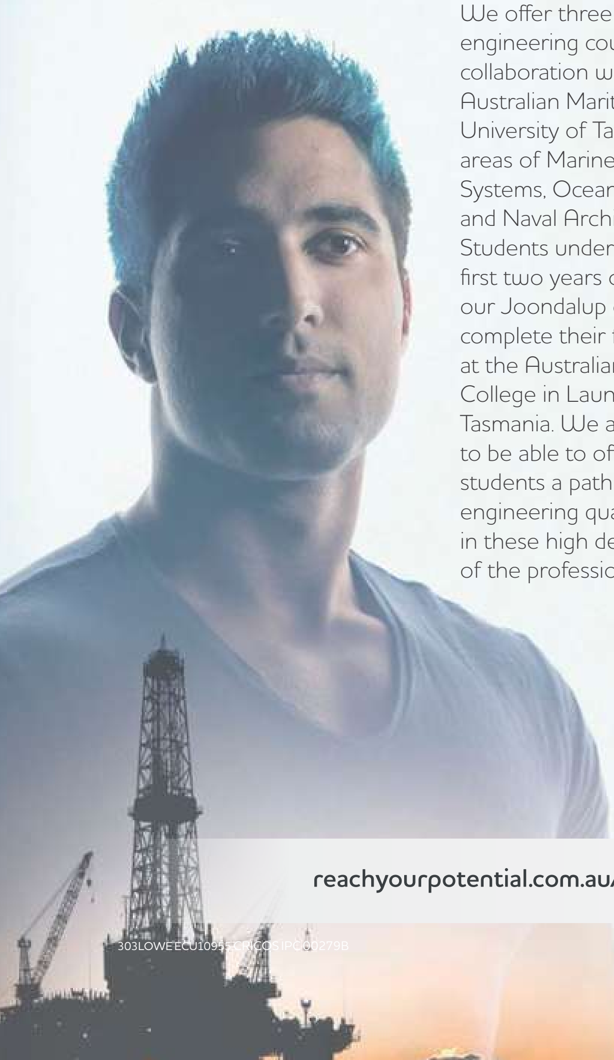
STUDY ENGINEERING AT EDITH COWAN UNIVERSITY

ECU's School of Engineering is one of the fastest growing Engineering and Technology Schools is in Australia.
Our courses are fully accredited by Engineers Australia and recognised under the Washington Accord. This means you'll graduate ready to design, test, build and solve real world challenges anywhere in the world.

"Nearly all units have a practical assessment, whether it's a lab or site investigation. This enhances our learning a great deal.

Bojan Markoski

ECU Civil Engineering student



WORLD CLASS FACILITIES

ECU Engineering students learn in world class, multimillion-dollar facilities featuring purpose built labs, many of which have been set up in collaboration with industry, like our automation and control laboratory developed in conjunction with our industry partner Schneider Electric.

"The new Engineering building is state-of-the-art and, after visiting other universities, I see how fortunate I was to study in such a fantastic facility."

Aaron Redman

Engineering Computer Systems graduate

THREE MARITIME ENGINEERING COURSES

We offer three maritime engineering courses in collaboration with the Australian Maritime College, University of Tasmania, in the areas of Marine and Offshore Systems, Ocean Engineering and Naval Architecture.
Students undertake their first two years of study at our Joondalup campus and complete their final two years at the Australian Maritime College in Launceston, Tasmania. We are excited to be able to offer WA students a pathway to engineering qualifications in these high demand areas of the profession.

PATHWAY TO ENGINEERING VIA BACHELOR OF TECHNOLOGY

At ECU, we believe everyone with the capability and aspiration to study engineering should have the opportunity to do so. Students who do not achieve the entrance requirements for the Bachelor of Engineering can enrol in the Bachelor of Technology. On successful completion of their first year of studies in this course, providing certain Mathematics and Physics units have been passed or exempted, students can apply for a transfer to one of the Bachelor of Engineering courses with advanced standing for all applicable completed units.

CONNECT, ENGAGE AND CREATE OPPORTUNITIES

The School of Engineering hosts an annual Careers Fair where students can meet representatives from various companies. Previous fairs have included Monadelphous, Wood & Grieve Engineers, Jacobs SKM (Sinclair Knight Merz), Georgiou Group, Clough, Main Roads Western Australia, Schneider Electric, Fortescue Metals Group and Worley Parsons.

At ECU, you can choose from our range of Engineering and Technology courses below:

- AERONAUTICAL
- AVIATION
- CHEMICAL
- CIVIL
- CIVIL & ENVIRONMENTAL
- COMPUTER SYSTEMS
- ELECTRICAL POWER
- ELECTRONICS & COMMUNICATIONS
- ELECTRONIC & COMPUTER SYSTEMS
- INSTRUMENTATION, CONTROL & AUTOMATION
- MARINE & OFFSHORE SYSTEMS
- MECHANICAL
- MECHATRONICS
- MOTORSPORTS
- NAVAL ARCHITECTURE
- OCEAN ENGINEERING

We also offer the following double degrees:

- ENGINEERING / BUSINESS
- ENGINEERING / LAW
- ENGINEERING / SCIENCE
- ENGINEERING (MECHATRONICS) / TECHNOLOGY (MOTORSPORTS)
- ENGINEERING (COMPUTER SYSTEMS) / COMPUTER SCIENCE

APPLY FOR ENGINEERING

reachyourpotential.com.au/engineering

Tel: 134 ECU (134 328)
E: futurestudy@ecu.edu.au

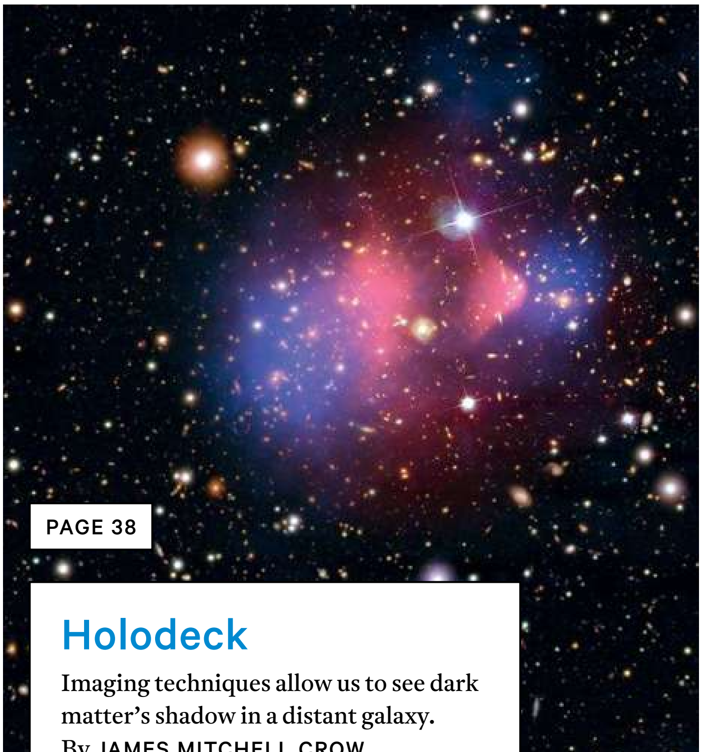
★★★★★ TEACHING QUALITY
★★★★★ GRADUATE STARTING SALARY
The Good Universities Guide 2016

COSMOS 65
COVER STORY & FEATURES

CONTENTS

CREDIT: BETTMANN / CORBIS

COSMOS 65
DISPATCHES, ESSAYS & REVIEWS



PAGE 38

Holodeck

Imaging techniques allow us to see dark matter's shadow in a distant galaxy.
By JAMES MITCHELL CROW.

WHY IS IT SO? — 124

SCIENCE FICTION — 103


AUSTRALIA'S SCIENCE CHANNEL
Ri Aus
riaus.tv
SUBSCRIBE TO A WORLD OF SCIENCE
sign up, it's free – riaus.tv

CONTRIBUTORS

ROBIN McKIE

Robin has been a regular contributor to *Cosmos* Magazine since its launch in 2005. He is also the science editor of *The Observer* in the UK and the author of several popular science books on genetics and human origins. He is based in London and is married with children. In December 2013, he was voted Science and Technology Writer of the Year at the UK Press Gazette Awards.

DAN FALK

Dan is an award-winning science journalist fascinated by space, time and the Universe. His writing credits include *Scientific American*, *Smithsonian* and *New Scientist*, and he's written three popular science books, most recently *The Science of Shakespeare*. Based in Toronto, in 2011-12 he was a Knight Science Journalism Fellow at the Massachusetts Institute of Technology.

ROBYN ARIANRHOD

Robyn is an Adjunct Senior Research Fellow in the School of Mathematical Sciences, Monash University. Her research fields are general relativity and history of mathematical science, for which she is also a technical reviewer for the American Mathematical Society. Her books include *Einstein's Heroes: Imagining the World through the Language of Mathematics*, and *Young Einstein and the story of $E=mc^2$*.

EDITORIAL
Editor-in-chief ELIZABETH FINKEL
Online editor JAMES MITCHELL CROW
Deputy editor BELINDA SMITH
Spectrum editor BILL CONDIE
Production editor KATHERINE KIZILOS
Art director ROBYN ADDERLY
Reporters VIVIANE RICHTER, MEGAN TOOMEY
Fiction editor CAT SPARKS
Editor-at-large WILSON DA SILVA

ADVERTISING
Advertising manager KAREN TAYLOR
+61 414 218 575
advertising@cosmosmagazine.com

MARKETING & COMMUNICATIONS
Digital marketing coordinator TESS WARDLE
Communications advisor ANDREW BRADLEY
+61 403 777 137
andrew@holdfastcommunications.com.au
Media relations BRIAN JOHNSON
+61 2 6582 3311

DISTRIBUTION
GORDON & GOTCH
Australia — 1300 650 666
New Zealand — +61 9 979 3018

SUBSCRIPTION & SALES
Subscriptions manager CHANTELLE VIANI
Publisher's assistant JACQUIE SMITH
+61 3 9829 0407
subscribe@cosmosmagazine.com
cosmosmagazine.com/shop

OFFICE CONTACT
Website cosmosmagazine.com
Editorial inquires info@cosmosmagazine.com
+61 3 9829 0408
PO BOX 254, Toorak Victoria 3142 Australia

COSMOS

Published by Cosmos Media Pty Ltd
ACN 137 559 187 ABN 65 137 559 187
Chairman & executive publisher ALAN FINKEL
Director DAVED LAMBERT
Associate publisher WAYNE GIBBINGS
Concept design STUDIO ROUND

Circulations Audit Board
September 2014 — Average Net Distribution 18226

65MAG0915

EDITOR'S NOTE

ELIZABETH FINKEL
Editor-in-chief

A nasty case of future shock

ANYONE OUT THERE EXPERIENCING a case of future shock? The book of that title was written in 1970 by Alvin Toffler. He defined the syndrome as "the shattering stress and disorientation that we induce in individuals by subjecting them to too much change in too short a time". Toffler was finding it hard to adjust to jet planes, satellite TV communication and the beginnings of IT – the first PC did not arrive until seven years later!

What must Toffler be feeling now?

I, for one, have been experiencing a nasty case of future shock over the last couple of months. The trigger was listening to the ABC *Science Show* on 25 July. Five days earlier Russian billionaire Yuri Milner had announced he was contributing $100 million dollars to invigorate the search for extra-terrestrial intelligence – the search has been orchestrated, so far, by the organisation SETI (Search for Extra-Terrestrial Intelligence). Astrophysicist Paul Davies, who chairs one of SETI's committees, was musing on the implications of success. If a signal were detected, say from Kepler 452b, the Earth-like planet whose discovery was announced on 23 July, it would have travelled 1,400 years to get here. By now, Davies said, those aliens would have evolved into artificial intelligences (AI).

Davies' matter of fact assumption shocked me. It shouldn't have. Many futurists predict we too will reach the singularity in the next couple of decades. The singularity? That is when machines achieve human intelligence and creativity – and start designing the next generation of smart machines. All bets are off as to what kind of superintelligence will evolve from that. Hans Moravec, an AI engineer at Carnegie Mellon, has dubbed these entities "tomorrow's children". The laws of nature will break down, as surely as they do in the singularity inside a black hole.

Adding insult to injury, the Monday after the *Science Show*, my inbox carried an open letter warning of the imminent danger of AI. It was signed by 1,000 attendees at an AI conference in Buenos Aires, including Elon Musk (CEO of SpaceX), Steven Wosniak (co-founder of Apple), Jaan Talinn (Skype co-founder) and physicist Stephen Hawking. They are worried about killer robots, such as autonomous drones that could be programmed to kill and then left to make their own decisions.

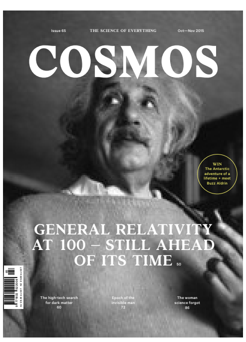
It's pretty scary when the world's greatest champions of science and technology are warning us about AI.

If that's not enough to give you a case of future shock, take a look at philosopher Laurie Zoloth's column in this issue. I'd always believed that the idea of "designer babies" was a figment of anti-science hysteria. After all we've had the technology to do this since the 1970s but haven't – it was a line in the sand we didn't cross.

But now, equipped with a vastly more precise new technology dubbed CRISPR, scientists *are* doing it. Even more startlingly, some ethicists think it's not a bad thing. The world's population is getting older and succumbing to the diseases of ageing: cancer and dementia. If we can design people to be relatively free of those diseases, shouldn't we do so?

Anyone else feeling a case of future shock?

ISSUE 65



COVER
The cover shows Albert Einstein at home in the US in his study in Princeton, New Jersey. The year is 1940. Einstein's genius was established. Twenty-one years had passed since he had published his theory of general relativity in 1915.

CREDIT: LUCIEN AIGNER / CORBIS

DIGITAL SUBSCRIPTION
Digital subscribers can now gain access to over nine years of archives and more.
Visit cosmosmagazine.com/shop

GIFT SUBSCRIPTION
Give the gift of science this Christmas. *Cosmos* Magazine gift subscriptions start from AU$25. Same price and free delivery worldwide.
See page 85 for details.

FOLLOW US
cosmosmagazine.com

CosmosMagazine
@CosmosMagazine

ISSN 1832-522X

Recommended retail price
$12.95 inc GST
(NZ$13.90 inc GST)

This issue on sale from
24 September 2015

PUBLISHER'S NOTE

ALAN FINKEL
Publisher

Science is relevant

TEENAGERS ARE OPTING OUT of science (see graph). Surveys point to various reasons, with one in particular that surprises me: 15 year olds, especially those growing up in technologically advanced countries, do not see science as relevant. The same teenagers are wired to their smartphones, rely on satellites to beam live tennis matches from the other side of the planet and know nothing of deadly diseases such as polio that were crippling Australian children only a few decades ago.

Our generation has somehow failed to impart the crucial importance of science to our children. I am concerned for two reasons. First, today's teenagers are tomorrow's work force. And they are in for a huge challenge. Thanks to robots and automation, nearly half of existing jobs are predicted to vanish within the next 20 years – and 75% of the jobs that replace them will require science and mathematics skills.

Second, today's teenagers will need to navigate a highly complex scientific world. Should they get their genomes read to better manage their health? Should they support more productive, genetically modified crops? Should they support geoengineering fixes to stop the planet from overheating?

Most students aren't thinking that far ahead. We need to capture their imagination before they make subject choices that will close the door marked "science". Science fairs, competitions and trips to the museum are insufficient. There's no doubt they offer a great experience, but they preach to the converted and don't reach all students. What we need are large-scale, appealing programs taught within the curriculum.

We are not shy of a challenge at *Cosmos* Magazine, so last year, after more than 12 months of development, we released *Cosmos Lessons*. They offer relevant science, aligned to the curriculum and taught within regular secondary school science classes. A new lesson is released to teachers every two weeks to ensure they stay relevant.

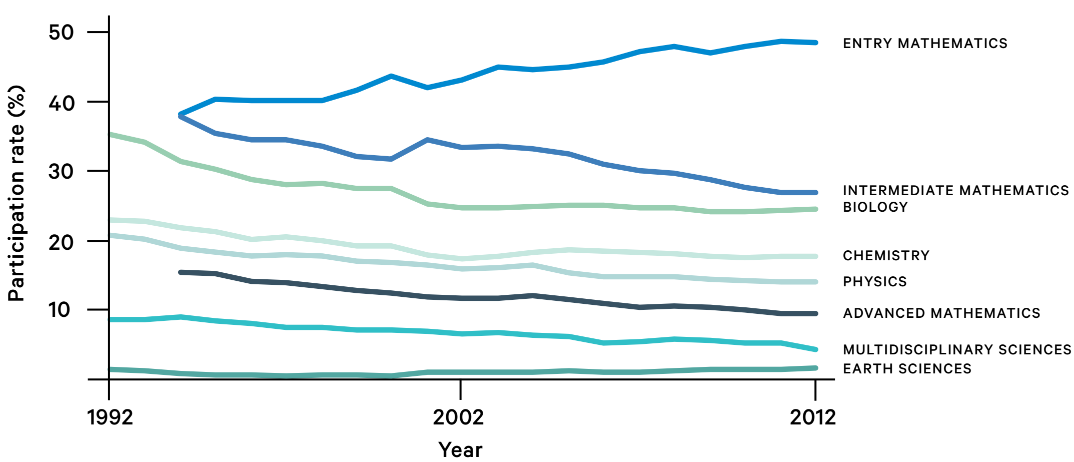
To my delight, uptake has been strong.

The secret of the success of *Cosmos Lessons* begins with their unique value proposition – each lesson is relevant to students because it is aligned to a recently published article in *Cosmos* Magazine. For example, our lesson on Newton's laws of motion was taught using the Google driverless car instead of sliding ice pucks; the recent Ebola outbreak was used to teach a lesson on the human body's innate immune system rather than the now eradicated smallpox disease.

I am personally committed to the development and delivery of *Cosmos Lessons*. They build on my experience with other secondary school science programs and in tertiary education.

I've seen many surveys that all point to the same problems in school science. We don't need more surveys. Instead we need solutions such as *Cosmos Lessons*.

AUSTRALIAN YEAR 12 SCIENCE & MATHEMATICS PARTICIPATION RATES



SOURCE: KENNEDY ET AL. 2014

FEEDBACK

WRITE TO US
Letters to the editor must include the writer's full name, address and daytime telephone number. They may be edited for clarity and length. Please do not send attachments.

SEND TO
letters@cosmosmagazine.com
Cosmos Magazine, PO Box 254, Toorak Victoria 3142 Australia
facebook.com/CosmosMagazine
@CosmosMagazine

COULD A MORE ACCURATE CLOCK CHANGE THE WORLD?

In 1736, John Harrison from Yorkshire set off a revolution in long distance sea travel. He did this by inventing an incredibly reliable marine chronometer. From that moment Britannia ruled the waves and the world suddenly became a lot smaller. Some 300 years later we now have a clock that can measure gravity ("The most accurate clock ever made", *Cosmos* Magazine 64). Is it now our galaxy that will become a lot smaller? I wonder.

— MATTHEW HUNT
Brisbane, Queensland

LOOKING FOR EARTH-LIKE PLANETS CLOSER TO HOME

To an interested layman, NASA's identifying of Earth-like planets such as Kepler 452b et al at distances too remote for even sci-fi to contact raise the question: are any planets orbiting a star some 4.5 to 20 light years from Earth candidates for Earth-likeness/life or are these too hard to distinguish at present? At least such planets might be contacted, or even reached when rockets are only used as a "first gear" to overcome gravity, and with an as yet to be invented propulsion to overcome astronomical distances. Thanking you for a fascinating, and reachable, magazine.

— FRED WEYERMAN
Frankston, Victoria

CULTURES DON'T ALWAYS TAME THE BEAST WITHIN

Wade Davis believes that anthropology teaches us that "culture is a body of moral and ethical values that every culture places around each individual being to keep at bay the barbaric heart that lies within all humans" ("Going Native", *Cosmos* Magazine 63). I would disagree, since sometimes cultures promote the expression of that same barbaric heart within us. I would say "good culture" has a noble goal of placing such values in position, rather than actually succeeding most of the time – and that includes all contemporary cultures, both modern and aboriginal. And that there are some really bad cultures out there as well.

— TED ARNOLD
via email

DISCOVERING A COSMOS IN AN UNEXPECTED PLACE

My hairdresser handed me a magazine recently. Yes, it was *Cosmos*. I started reading, and three articles in from the front, rang your subscriptions number and signed up for two years. Have never before come across a mag where every article is not only of interest, but written in a way that non-scientific people can understand and enjoy. Great for keeping the mind active, so a heartfelt thank you from me.

— JULIE EDWARDS
Launceston, Tasmania

THE BIG BANG QUESTION

I am not a scientist. I am 75 and have been retired for the last five years. My question, very simply, is what happened before the Big Bang? I may be hung up over cause and effect. But something must have caused the Big Bang. Otherwise we have a Big Bang that came from nothing. That doesn't sound scientific to me. I know about the multiverse theory and the cyclical universe theory but it seems to me that they just raise other issues. I just don't understand these theories either. I do not believe a God created the Universe but could someone give me a convincing explanation of how the Big Bang occurred?

— VANCE GREY,
Auckland, New Zealand

REPLY FROM DEPUTY EDITOR JAMES MITCHELL CROW:

Vance, your guess is as good as Stephen Hawking's on this one. At the moment of the Big Bang, all the matter in the Universe was squeezed together into a "singularity" of infinite density. By applying the laws of physics, we can retrace time to a fraction of a second after the Big Bang. But at the point of singularity, these laws break down and we can rewind no further.

COSMOS ONLINE

WIN AN ANTARCTIC ADVENTURE

Subscribe, renew or give *Cosmos* Magazine as a gift this Christmas and go into the draw to win a scenic flight to Antarctica for you and a friend thanks to Antartica Flights. Offer ends 22 December 2015.

→ cosmosmagazine.com/shop

COMPETITION

WIN A MEET & GREET WITH BUZZ ALDRIN

Cosmos Magazine together with Live on Stage Australia is giving our readers an opportunity of a lifetime for two lucky people to meet Buzz Aldrin pre-show at An Evening with Buzz Aldrin: Mission to Mars at either the Melbourne or Sydney event. Competition ends 8 October, winners will be anounced 9 October. To enter visit link below.

→ cosmosmagazine.com/competitions

WEB

THE END OF SPACE EXPLORATION?

Plutonium powers New Horizons' study of Pluto but our stocks are running low. Richard A. Lovett reports on the alternatives.

→ bit.ly/SpaceEnd

BLOG

SUPERMASSIVE BLACK HOLE IN NEARBY QUASAR

Astrophysicists have found two supermassive blackholes in Markarian 231, the nearest quasar to Earth.

→ bit.ly/BlackHoleQuasar

FOLLOW US

Join our 325,000+ followers at facebook.com/CosmosMagazine

Follow our tweets @CosmosMagazine

Follow our authors
@AstroKatie
@belindie
@iCatHalo

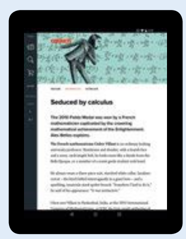
Stay on top of our latest posts on the *Cosmos* newsblog blog.cosmosmagazine.com

Subscribe to our YouTube channel at bitly.com/CosmosTube

Subscribe to *Cosmos* Magazine from $A25 at cosmosmagazine.com/shop

Tell us what you think! cosmosmagazine.com/feedback

DIGITAL



Read Cosmos on your phone, tablet or computer. Plus listen to our weekly podcast at cosmosmagazine.com/podcast

LEADERS

ISSUE 65

ADVANCES IN MATHS AND PHYSICS CHANGED OUR WORLD VIEW

No apologies: this issue of *Cosmos* Magazine is a brain bender. We celebrate the 100th birthday of Einstein's theory of general relativity which he published in four papers in November 1915. The maths is difficult for the average reader, but it is possible to understand the implications. Space and time, Einstein realised, were not the inert stage upon which the events of the Universe play out. Space-time is its very fabric. And it is malleable. Gravity warps it and everything in the Universe is affected: planets, stars, the light from those stars and even time.

All these fantastical predictions have been confirmed in the century since Einstein made them, as instruments pushed the limits of what we can measure: telescopes saw how starlight is bent and atomic clocks divided time into such fine intervals they could measure how gravity stretches those intervals. Yet general relativity is still ahead of its time. We have not yet measured the gravitational waves that Einstein predicted are rippling the fabric of space-time. More than half a billion dollars has been spent on an extraordinary set of machines called LIGO in the US that are waiting to detect these ripples. So far LIGO has been tuning in for 10 years – and heard nothing. Now its sensitivity has been doubled. The physicists predict success is nigh.

Next up, dark matter. For the last 80 years astronomers have not been able to detect enough matter in the Universe to explain what holds galaxies together while they spin. So either something is awry with our understanding of gravity and the theory of general relativity needs adjusting, or there is a mysterious type of matter out there that is five times more plentiful than ordinary atoms. The Large Hadron Collider – the multi-billion dollar atom smasher – is now trying to make some. And around the world, detectors, including one planned for Victoria, Australia at the bottom of the Stawell gold mine, are trying to glimpse these dark particles. Dark matter physicists are also confident success is nigh.

How did we ever come up with such scientific theories? To reflect on how maths and physics has taken us into these extraordinary realms take a look at Robyn Arianrhod's piece about Newton and his champions Émilie du Châtelet and her lover, Voltaire.

WOMEN PIONEERS EXTEND WHAT HUMANS BELIEVE IS POSSIBLE

Two women pioneers in physics and mathematics are celebrated in this issue. Both were able to see what others could not and succeeded despite many obstacles.

Voltaire described Émilie du Châtelet as a "great man whose only fault was being a woman". A French aristocrat, she has largely been remembered for being Voltaire's mistress, although Voltaire regarded her as a genius in her own right. Together they wrote a book on Newton's philosophy (only Voltaire's name appeared on the title page). In reality du Châtelet explained Newton's mathematics to Voltaire. He told a friend "she dictated and I wrote".

Du Châtelet's most important work was translating Newton's treatise on gravity into French from the original Latin. In so doing, she explained Newton's mathematics in prose, translated his geometry into calculus and described the latest Newtonian research. The work is still considered the standard French translation.

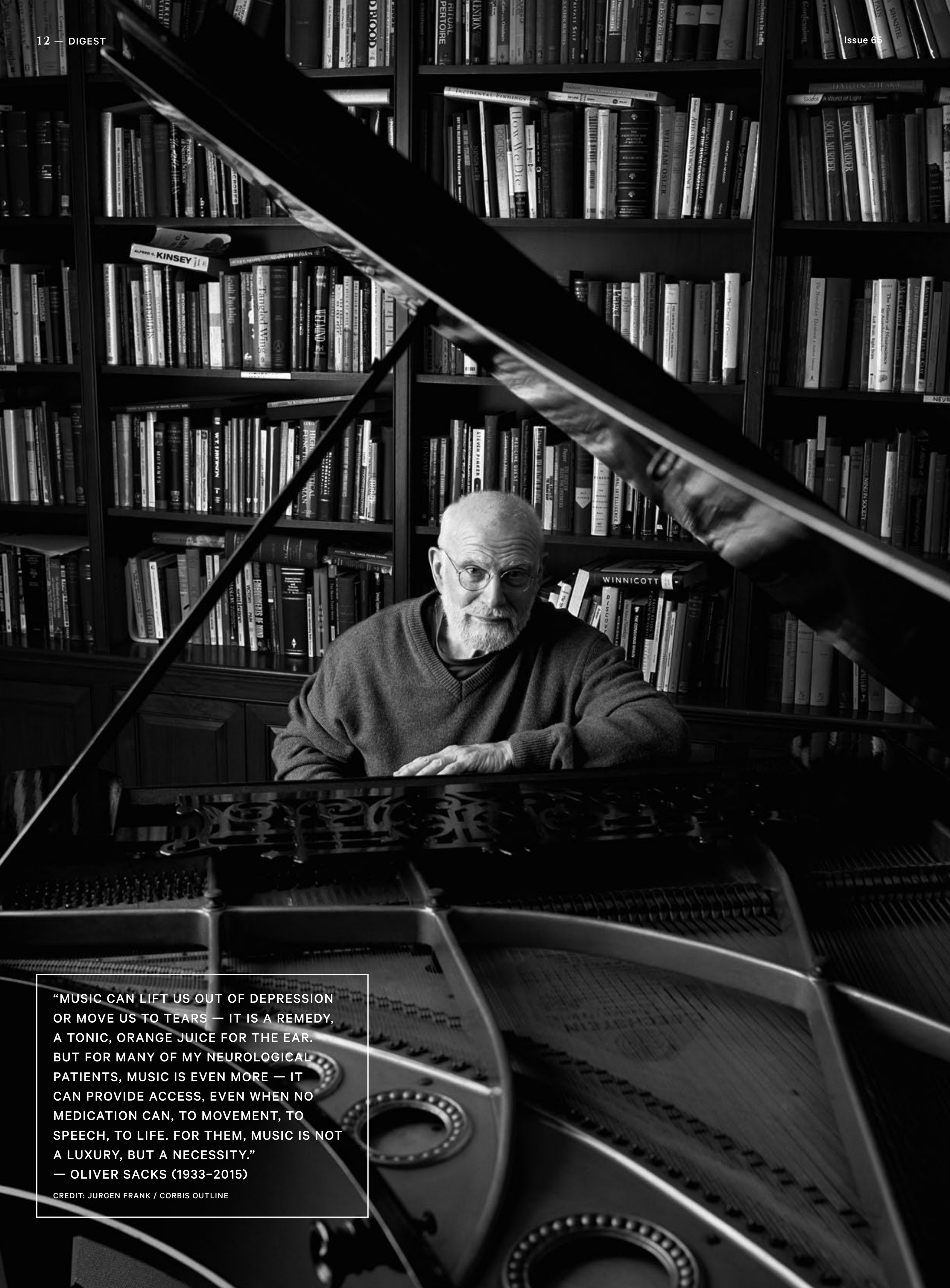
In her personal life du Châtelet was a fearless non-conformist; a quality that extended to her intellectual life. In her day women did not attend universities – the young Émilie had home tutors. Du Châtelet recognised her ability to pursue her intellectual interests and make a scientific contribution was a rare privilege. She became a strong advocate for female secondary school education.

The German-Jewish mathematician Emmy Noether was born 172 years after du Châtelet. She *was* able to attend high school in Bavaria, but faced obstacles when trying to enrol in university. She succeeded because of her brilliance and persistence, aided by her humility. German universities did not pay Noether a salary for years. A colleague described her as "completely unegotistical and free of vanity, she never claimed anything for herself, but promoted the works of her students above all".

Noether was Einstein's contemporary. Both sought refuge from the Nazis in the US. Einstein considered Noether to be "the most significant creative mathematical genius thus far produced since the higher education of women began". The description acknowledges that education is a means of unlocking potential – for individual women certainly, but also for humanity. Noether and du Châtelet deserve to be remembered – for the contribution they made, for the obstacles they overcame and for the example they provide to anyone who values what free and fearless minds can achieve.

Emmy Noether, the German mathematician who succeeded against formidable odds.

CREDIT: SCIENCE PHOTO LIBRARY / GETTY IMAGES



"MUSIC CAN LIFT US OUT OF DEPRESSION OR MOVE US TO TEARS — IT IS A REMEDY, A TONIC, ORANGE JUICE FOR THE EAR. BUT FOR MANY OF MY NEUROLOGICAL PATIENTS, MUSIC IS EVEN MORE — IT CAN PROVIDE ACCESS, EVEN WHEN NO MEDICATION CAN, TO MOVEMENT, TO SPEECH, TO LIFE. FOR THEM, MUSIC IS NOT A LUXURY, BUT A NECESSITY."
— OLIVER SACKS (1933–2015)

CREDIT: JURGEN FRANK / CORBIS OUTLINE

A CLOSER LOOK AT THE BIG STORIES

DIGEST

SPACE

Pluto in close-up

Stunning images beamed back to Earth by New Horizons have enhanced Pluto's mystique. By RICHARD A LOVETT.

As recently as June, Pluto was one of the most mysterious objects in the Solar System – so remote scientists weren't even sure of its size. Today, we not only have a clear measure of its diameter (2,370 kilometres, give or take 20 kilometres), but we know it has a red-streaked polar cap, steep →

Detailed pictures of Pluto taken by the New Horizons spacecraft have revealed a smooth ice cap near its equator, with flowing glaciers.

CREDIT: NASA / JHUAPL / SWRI

mountains nearly as tall as New Zealand's Mount Cook, and a surface so fresh and smooth that scientists think it might still be geologically alive.

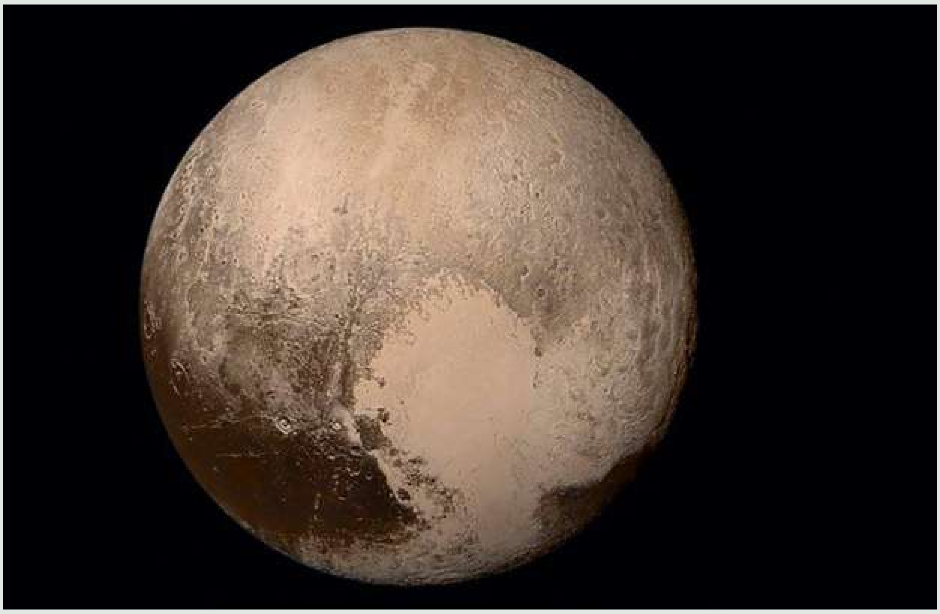
Furthermore, Pluto's giant moon Charon turns out not to be a dead, cratered landscape like the Earth's Moon, but has its own reddish polar cap, enormous canyons up to 10 kilometres deep, and a surface that suggests recent geological activity.

These findings have been beamed back to Earth since the New Horizons spaceship finally zoomed past Pluto early on 14 July. The little spacecraft had travelled five billion kilometres since leaving Cape Canavarel on January 19, 2006.

Colour pictures taken by New Horizons reveal a remarkably complex Pluto with several distinct geological provinces, including a bright, heart-shaped feature the size of Texas.

The heart appears to be composed of two distinct regions, tinted white on the left and blue on the right. It is flanked on one side by giant mountains, probably made of water ice, 3,400 metres high. The heart's interior appears to be a broad icecap. And fringing this icy heart, glaciers of this "ice" – carbon monoxide, methane and nitrogen – appear to have flowed (and may still be flowing) into the surrounding lowlands.

On Pluto, where the average temperature is around -230°C, water would be frozen too hard to flow, but that is not the case for these frozen gases.



Pluto has a heart the size of Texas. CREDIT: NASA / JHUAPL / SWRI

The halo around Pluto reveals the dwarf planet's atmosphere – a phenomenon scientists don't yet understand.

CREDIT: NASA / JHUAPL / SWRI

"This is not an ancient landscape," says John Spencer, a planetary scientist from the Southwest Research Institute in Boulder, Colorado. "We think it has to be less than 100 million years old" – a blink of an eye, in geological terms.

How a cold, tiny world such as Pluto can have been recently geologically active – let alone active enough to form a smooth new crust over much of its surface and produce mountains comparable in height to some of the Earth's great ranges – is baffling.

"This is a landscape that has been reshaped by forces from the interior of Pluto that we don't begin to understand," Spencer says.

The conventional wisdom has been that a small icy world can only be active when there's a massive planet such as Jupiter or Saturn nearby, which have a gravity that exerts a tidal tug, distorting the smaller world and warming its insides through friction.

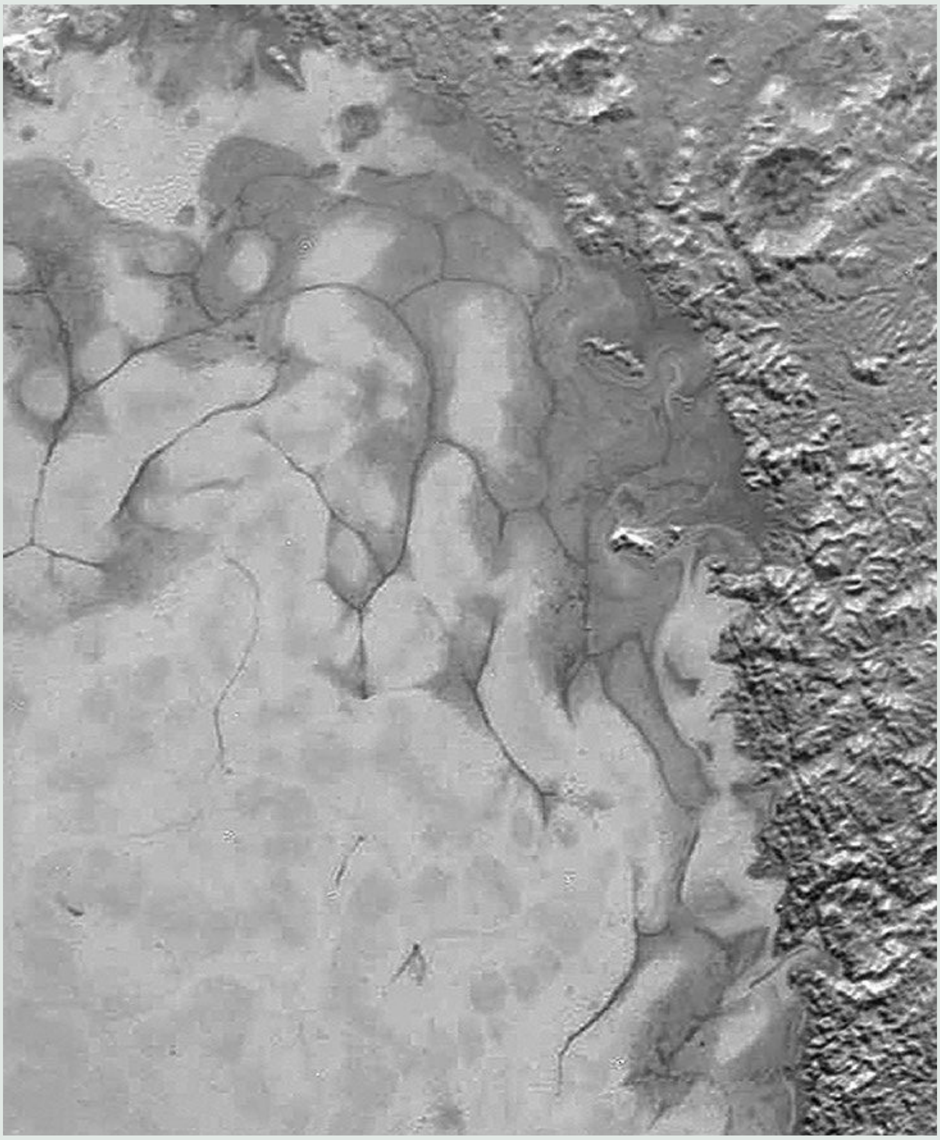
"But that can't happen on Pluto," he adds. Charon might be big for a moon, but it isn't capable of producing such gravitational energies in its present orbit. And Pluto is well out of the gas giants' gravitational reach.

The discovery is "going to send a lot of geophysicists back to the drawing board to try to figure out just how that can be", Spencer says.

The images taken by New Horizons of Pluto's fine hazy upper atmosphere pose another puzzle. This haze appears to be concentrated in layers several kilometres thick, the most prominent of which were seen at around 50 and 80 kilometres above the dwarf planet.

"THIS IS A LANDSCAPE THAT HAS BEEN RESHAPED BY FORCES FROM THE INTERIOR OF PLUTO THAT WE DON'T BEGIN TO UNDERSTAND."

Although astronomers were aware that Pluto had an atmosphere before New Horizons set out on its mission, nobody is sure why these atmospheric layers exist says Michael Summers, a planetary scientist from George Mason University in Virginia and a co-investigator on the mission. "We're having to start from scratch, changing what we thought we knew about Pluto's atmosphere," he says. (Scientists speculate the haze is probably made of tiny hydrocarbon droplets, cobbled from the remnants of atmospheric methane molecules split by the Sun's ultraviolet light.)



Glaciers and lofty ranges frame the edge of Pluto's heart. CREDIT: NASA / JHUAPL / SWRI

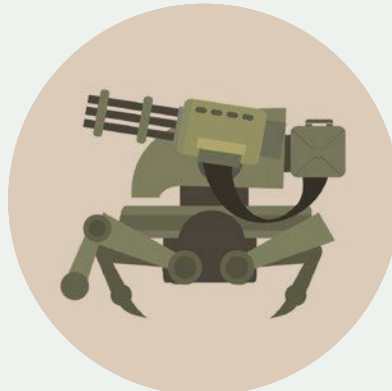
Summers says the haze is thin. "If you were on the surface of Pluto, you probably would not see it," he says.

Measurements taken by New Horizons also suggest Pluto is rapidly losing its atmospheric mass. Because of its extreme elliptical orbit Pluto has been moving steadily outward from the Sun and getting colder since its closest approach in 1989. The molecules in the atmosphere can "freeze out", settling on the surface like frost. Scientists have long speculated that by the time Pluto reaches its furthest point in 2113 – nearly half again as distant from the Sun as its present position – its atmosphere will have frozen out completely. But if the latest measurements are correct, they show the atmospheric mass has halved in the past two years. Nobody anticipated Pluto's atmosphere would freeze out this rapidly.

Scientists expect more surprises in the images still to come. Information from New Horizons takes four and a half hours to reach the Earth, and is transmitted at about two kilobits per second, which is slower than internet dial-up speeds. At that rate, it will take more than a year for all of New Horizons' flyby data to be received. In the meantime, Pluto has not disappointed. As Alan Stern, principal investigator of the mission, says: "I don't think any of us could have imagined that it was this good a toy store."

IN BRIEF

KILLER ROBOT WARNING



AN OPEN LETTER calling for a ban on offensive autonomous weapons – so-called killer robots – and warning of a "military artificial intelligence arms race" has been signed by leading AI researchers.

The deployment of "autonomous weapons is – practically if not legally – feasible within years, not decades, and the stakes are high: autonomous weapons have been described as the third revolution in warfare, after gunpowder and nuclear arms," the letter states. "The endpoint of this technological trajectory is obvious: autonomous weapons will become the Kalashnikovs of tomorrow."

Signatories include Tesla chief executive Elon Musk and Apple co-founder Steve Wozniak.

"Autonomous weapons are ideal for tasks such as assassinations, destabilising nations, subduing populations and selectively killing a particular ethnic group," the letter says. "A military AI arms race would not be beneficial for humanity."

— *COSMOS* MAGAZINE EDITORS

LIFE SCIENCES

Single-cell eyeball creature startles scientists

A rare sea creature can teach us about the eye's evolution. By VIVIANE RICHTER.

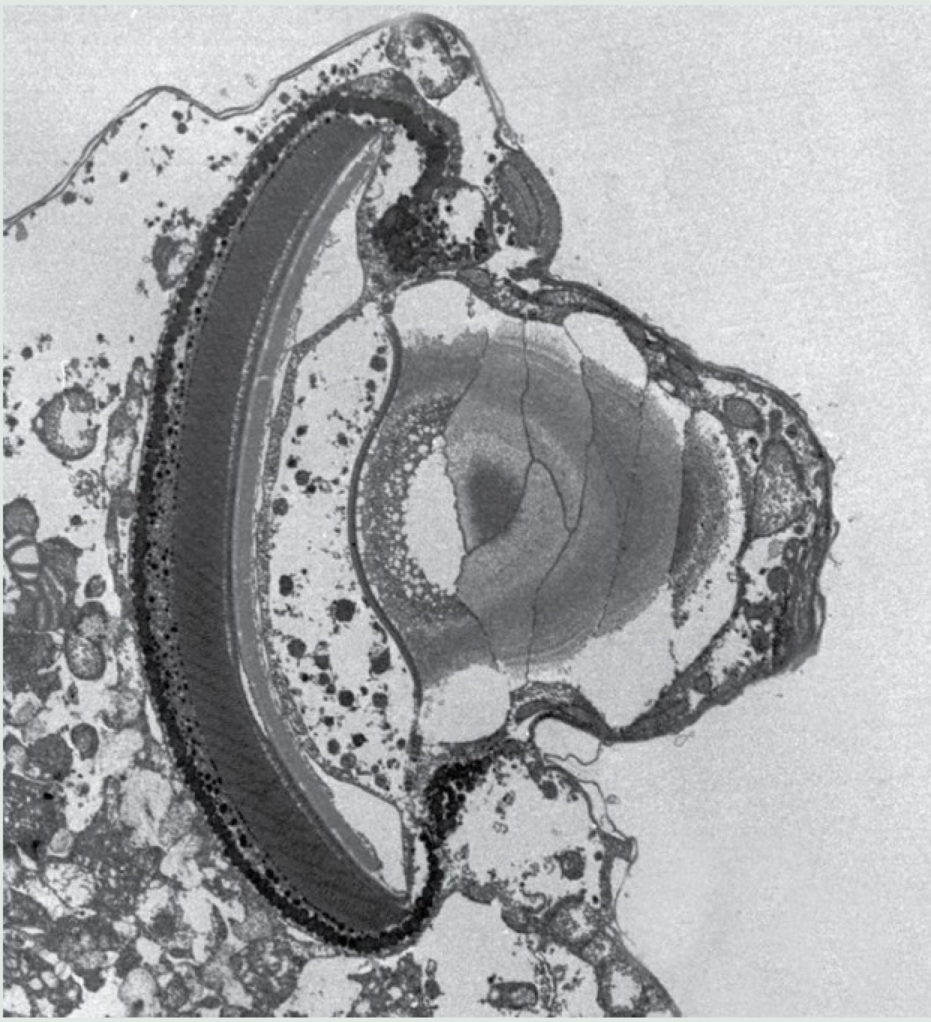
Peering down the microscope at a single-celled marine creature, Greg Gavelis was startled to find a tiny floating eyeball staring back at him.

It possessed many of the features of the human eye, including a lens, cornea and retina. Gavelis, a zoology student at the University of British Columbia, and his colleagues published the work in *Nature* in July.

"It's really interesting that you can get complex eye structures at a subcellular level," says Thomas Richards, an evolutionary biologist at the University of Exeter. "And what's so striking is they figured out how the components evolved."

The eye has evolved independently multiple times, to form structures as complex as the eye of a squid or a human.

The idea that the eye could have formed by natural selection seemed "absurd in the highest possible degree" wrote Darwin in *On the origin of species*. He reasoned that the eye must have evolved in little steps from a basic light-sensing organ to achieve increasing complexity in multicellular creatures.



The warnowiid eye. CREDIT: GREGORY GAVELIS / UNIVERSITY OF BRITISH COLUMBIA

But the warnowiid seems to have taken a shortcut. Researchers first stumbled across one more than a century ago, and guessed then that its dark purple spot might be an eye.

But getting more details proved difficult. Not only is the warnowiid extremely rare – found in tiny numbers off the coast of Canada and Japan – but it rapidly disintegrates after being taken out of seawater.

To catch his own warnowiid, Gavelis searched seawater samples under a microscope for a year.

When he eventually found one he froze it in plastic resin, preserving it like a fly trapped in amber. He then made a 3-D model by taking snapshots of the warnowiid under an electron microscope – and was stunned by what he saw.

Other single-celled creatures can detect light using "eyespots" – simple pigmented structures that allow an organism to tell dark from light. But the warnowiid appears to have gone further – repurposing cellular bits and pieces to form what resembles the lens, cornea, iris and retina of a complex eye.

Like our own eyes, the creature's lens consists mainly of proteins.

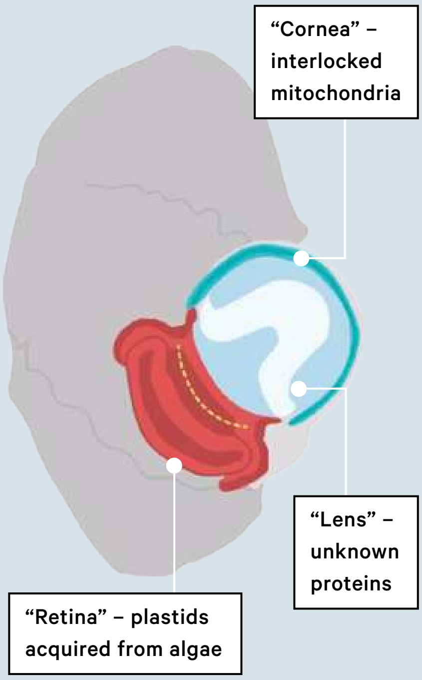
But other components show a creative use of cellular organelles. The "cornea" for example – the transparent protective outer layer at the front of the eye – is made of mitochondria, the bits of the cell normally responsible for energy production. To form the cornea, the mitochondria appear to have interlocked into a sheet-like layer around the lens, that curves to concentrate incoming light on to the "retina".

AT SOME POINT DURING EVOLUTION A WARNOWIID ANCESTOR GOBBLED UP SOME ALGAE AND ADOPTED ITS PHOTOSYNTHETIC EQUIPMENT.

The light-sensing "retina" at the back of the eye is made up of plastids – light-sensitive structures that are normally involved in photosynthesis. Hundreds of them were lined up in parallel. It "is reminiscent of the polarising filters on the lenses of cameras and sunglasses", says a

HOW IT WORKS

The single-celled creature has repurposed basic components for its eye.



co-author of the paper, Brian Lender.

The DNA from the warnowiid's plastids showed it once belonged to algae. The team suspects that at some point during its evolution, a warnowiid ancestor gobbled up some algae and adopted its photosynthetic equipment.

When the organism later abandoned photosynthesis for the predatory life, it repurposed its light-capturing plastids into a light-sensing organ.

It is not clear how warnowiids use their "eye", but it may be used to help these hunters harpoon their prey.

Warnowiids spiral through the water as they swim and Gavelis thinks the eye lets them see flashes of light as it bounces off the single-celled plankton they hunt. The lens likely concentrates incoming light to increase sensitivity – rather than projecting an image as our own eye does.

"Critics of evolution often talk about how there are no transitional forms of eyes," says Gavelis. "But they're alive and well in this case."

BY THE NUMBERS

RIDING THE JET STREAM

4.6 MILLION

The extra carbon dioxide, in kilograms per year, added into the atmosphere by 2100 from four airlines that fly between the west coast of the US and Hawaii. The airlines hitch a ride on the jet stream, which is predicted to shift as a result of climate change.

1.4 MILLION

The cost, in US dollars, of extra fuel per year for each airline flying these routes.

30,000

The approximate number of commercial domestic flights that take off per day in the US.

250,000

The number of flights analysed as part of the study, published in *Nature Climate Change* in July.

10 BILLION

The extra CO_2, in kilograms per year (approximately), that will be emitted should each US domestic round trip require an extra one minute's flying time due to shifting wind patterns.

DISCOVERY

Oldest stone tools ever found

Stone tools made 3.3 million years ago have been found in Kenya. JAMES MITCHELL CROW reports.

A 3.3 million year old stone tool recently unearthed near Lake Turkana in Kenya, which advances our understanding of our early ancestors. CREDIT: MPK-WTAP

A chance find in the Rift Valley of north-west Kenya sheds new light on the history of our species.

Archaeologists have discovered stone tools created by our ancestors 3.3 million years ago – considerably older than the 2.6 million year old Oldowan stone tools that were previously the oldest stone tools ever found. The discovery at the Lomekwi 3 site near Lake Turkana was led by Sonia Harmand at Stony Brook University in New York and reported in the journal *Nature* in May.

Until recently it was generally thought that our ancestors only became sufficiently intelligent to make complex stone tools with the emergence of *Homo habilus* – a name that translates as 'the handy man' – who lived in Africa around the same time as Oldowan tools appear in the archaeological record.

ASIDE FROM HUMANS, CHIMPS ARE THE ONLY OTHER SPECIES KNOWN TO USE STONE TOOLS.

The new discovery overturns that idea. The tools were created when ape-like species such as *Kenyanthropus platytops* and *Australopithecus afarensis* – of which the fossil Lucy was a member – are known to have roamed this part of Africa.

The newly discovered tools are certainly more primitive than the Oldowan stone tools that appeared 700,000 years later.

But whoever made the Lomekwi tools apparently had more brainpower than today's chimps. Aside from humans, chimps are the only species known to use stone tools, using one rock to crack open a nut placed on another rock, for instance. But chimps do not deliberately crack rocks together to create cutting tools.

Around 1.7 million years ago, Oldowan tools began to be replaced by Acheulean blades, which were created by means of a more sophisticated flaking technique which was further refined over time.

The chances are the Lomekwi 3 tools will not turn out to be the first stone tools our ancestors created.

In 2009, researchers at Dikika, Ethiopia, dug up 3.4 million year old animal bones bearing cut marks that seem to have been created by somebody using a sharp-edged stone to trim flesh from bone and perhaps crush bones to get at the marrow inside.

Oldowan stone tools, named after the Olduvai Gorge in Tanzania where they were first discovered, are created by carefully chipping away flakes of rock to produce a sharp edge.

CREDIT: JAVIER TRUEBA / MSF / SCIENCE PHOTO LIBRARY

TECHNOLOGY

Concrete buildings that heal themselves

Bacteria spores are part of a new ecological concrete mix. VIVIANE RICHTER reports.

A living concrete that repairs its own cracks is in the works. Hendrik Jonkers, a microbiologist at Delft University in the Netherlands, made this revolutionary product by placing spores of mineral-excreting bacteria in the concrete mix.

"I think it's a good solution," says Rackel San Nicolas, materials and civil engineer at the University of Melbourne. "This process is more ecological than what we currently use."

Concrete goes back to ancient Rome where it was used to construct the Pantheon and Colosseum, massive structures that are still standing today. But both are less than 50 metres tall, whereas modern skyscrapers can be hundreds of metres high. This is possible because in modern buildings liquid concrete is poured around a steel scaffold. The steel increases a structure's tensile strength, making it less prone to breaking. Eventually, however, the steel can become a liability.

Concrete is slightly porous and after 20 or 30 years water can seep into it, carrying corrosives such as CO_2, chloride, or sea salt that reacts with the steel inside the concrete. As steel starts to rust, it expands and pushes on the concrete, eventually forming cracks.

Fixing the damage with plaster or steel plates is costly: about $6.5 billion is spent on concrete renovations in the European Union alone each year.

So Jonkers wondered if bacteria could be used to make a self-healing concrete. One obstacle is that concrete is too alkaline for most bacteria to survive in it. But Jonkers spent his early career researching extremophiles – organisms that thrive in normally inhospitable places – and had "a good hunch" that *Bacillus pseudofirmus* and *B. cohnii* might do the trick.

Extremophiles are usually found in volcanic rocks or swimming in alkaline soda lakes. Their spores can survive at a pH of 12-13, which is exactly the pH of concrete.

To create his now patented "bio-concrete" Jonkers spikes normal wet concrete with an equal ratio of his bacterial spores and their food, calcium lactate. This mixture makes up 1% of the final concrete mix. As the concrete dries, the spores are entombed in the slab.

The spores can lie dormant for at least 200 years until air and water enter a crack. The activated spores then start munching on the food around them and excrete carbonate ions, which react with calcium in the concrete to produce limestone mortar. Once the crack is filled the bacteria are stifled by their own waste and die.

Jonkers' bacteria take three weeks to seal cracks in concrete. They can only fill fine cracks – up to 0.8 millimetres wide – but an early repair stops them from getting bigger. The bacteria can heal existing structures too, by way of a spray-on formulation, that eat, excrete and seal fine cracks.

The spray will be on sale late this year, with the bio-concrete due to be rolled out in 2016. Bio-concrete is 50% more expensive than conventional concrete, but Jonkers is confident the long-term savings will outweigh the initial cost.

For underground structures that are more exposed to moisture, he has calculated the bio-concrete would pay for itself within two years of the first cracks appearing.

San Nicolas agrees the technology could significantly extend a building's life, but adds "it will fix the problem for a while but not forever".

Jonkers is partnering with a Dutch company, Verdygo, that will use his bio-concrete to build a wastewater treatment plant in Limburg.

Should spore-laden buildings rouse our safety concerns? Not at all, says San Nicolas: "We've got bacteria everywhere."

IN BRIEF

SEARCH FOR SMART ALIENS

Yuri Milner and Stephen Hawking are backing the seach for intelligent life.

CREDIT: STUART C. WILSON / GETTY IMAGES

RUSSIAN ENTREPRENEUR Yuri Milner has intensified the search for alien intelligent life.

He has committed $100 million in funds for the project, which has the backing of physicist Stephen Hawking.

The Breakthrough Prize Foundation program will use three of the world's largest and most capable radio telescopes – the Parkes Radio Telescope in Australia, the Green Bank Telescope and Lick Observatory in the US.

The search will be 50 times more sensitive, and cover 10 times more sky, than previous hunts for alien life.

"It's time to commit to finding the answer, to search for life beyond Earth," said Hawking.

"Mankind has a deep need to explore, to learn, to know. We also happen to be sociable creatures.

"It is important for us to know if we are alone in the dark."

— *COSMOS* MAGAZINE EDITORS

SPACE

The first stars in the Universe

Scientists believe they have sighted the Universe's earliest stars.
CATHAL O'CONNELL reports

The Universe began with a brilliant flash but soon descended into darkness. And then, a few hundred million years after the Big Bang, the first stars flickered into life.

Astronomers believe they have now glimpsed some of these pioneers. The ancient ancestors of modern stars were monsters, hundreds of times more massive than our Sun and millions of times as luminous. Their short, intense lives ended in giant supernova explosions, enriching the cosmos with the first elements heavier than helium, including carbon, oxygen and nitrogen – the stuff of planets and of life.

Many astronomers thought we'd never glimpse these ancient 'population III' (or pop-III) stars. But tantalising evidence has come from a galaxy that is 12.9 billion years old and by far the brightest ever seen from its epoch.

The Very Large Telescope platform at the Paranal Observatory in Chile's Atacama Desert. The telescope was used to conduct the largest survey of the ancient Universe.

CREDIT: ESO

David Sobral at Leiden Observatory in the Netherlands and his team spied a vast, diffuse pocket of pure hydrogen and helium gas glowing within the galaxy with the European Space Organisation's Very Large Telescope in Chile's Atacama Desert.

The lack of other elements indicated the gas was pristine material from the beginning of creation – the Big Bang itself no less. The team reasoned that the galaxy's unusual characteristics could be explained by ancient pop-III stars lurking within it. Their hypothesis was published in *The Astrophysical Journal* in July.

"It doesn't really get any more exciting than this," says Sobral.

In the mid-20th century, astronomers noticed the Universe contains two distinct populations of stars. Population I, the first stars they identified, were like our Sun, rich in metals (astronomers call any element heavier than helium a metal) and located around the fringes of galaxies. A second group, dubbed pop-II, formed earlier than pop-I, were relatively poor in metals, and were situated near the cores of galaxies.

It was only after the Big Bang theory was accepted that astronomers reasoned that, since only hydrogen and helium were created in the Big Bang, there must have been an earlier population of stars containing no metals at all.

Astrophysicists soon realised these pop-III stars would be special. Stars form when a hot cloud of gas cools to the point that gravity takes over and the cloud collapses in on itself. A rapidly cooling cloud, such as one with heat-absorbing metals that speed up the process, spawns many small stars, but a slowly cooling cloud produces monsters.

Because the clouds that spawned pop-III stars contained no heavier elements, these early stars could grow to an extraordinary size. A pop-III star would blaze with the brightness of a million suns. With a huge gravity powering their nuclear fusion, these stars would churn through their stock of hydrogen in only a few million years – a brief life by astronomical standards.

Would we ever glimpse these titans? To look back in time, we need to peer deep into the Universe. But whether we'd ever detect the faint and distant light of pop-III stars was a big question, says Amanda Bauer, an astrophysicist at the Australian Astronomical Observatory.

Sobral and his team discovered the ancient galaxy by conducting a celestial survey that was about 10 times larger than the largest surveys previously attempted. This galaxy, CR7, stood out like a beacon – three times brighter than other galaxies from its epoch. "Once you look where no-one's looked, there's always the potential for interesting discoveries," Sobral says.

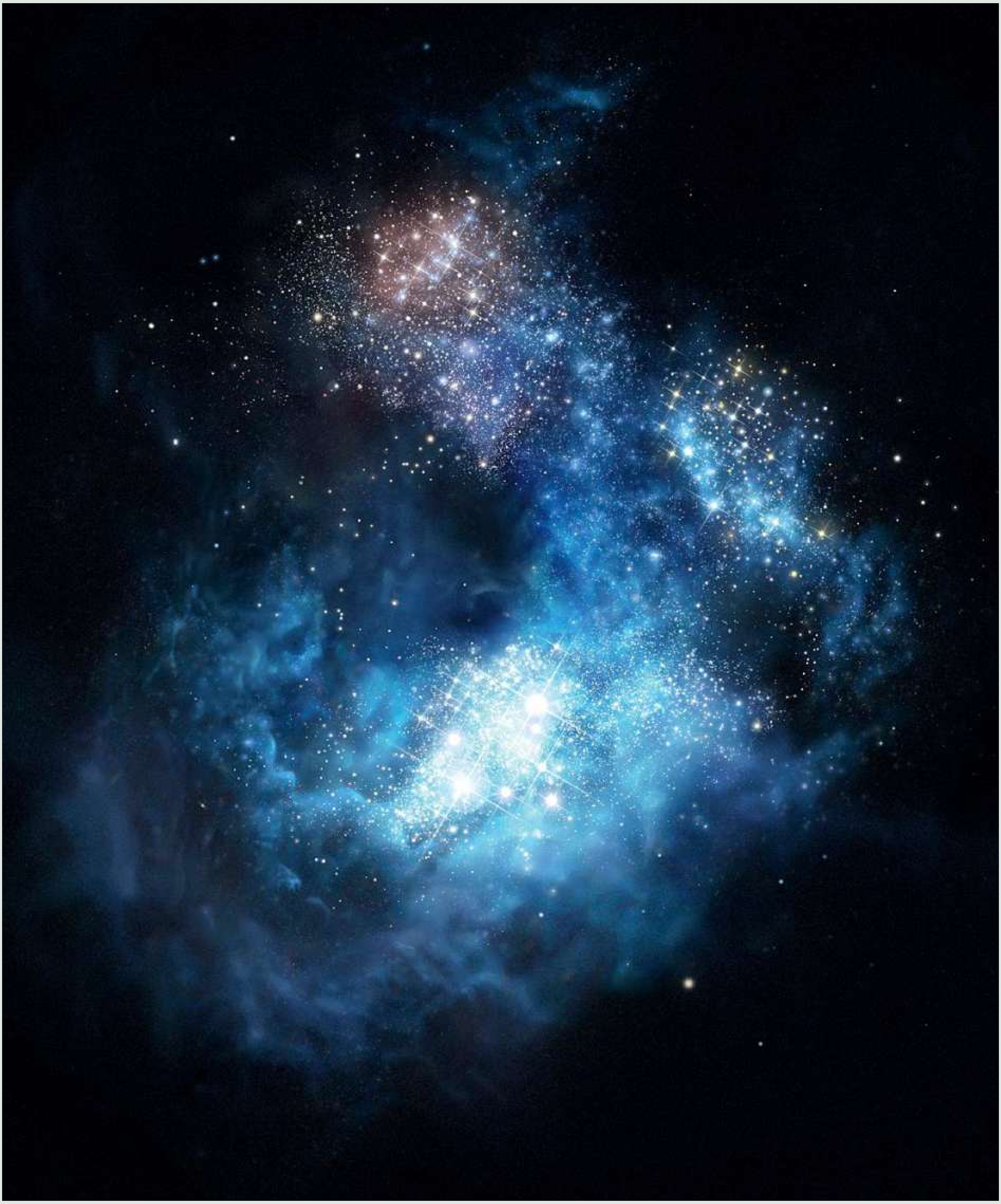
The light reaching Earth from CR7 was emitted 800 million years after the Big Bang, long after the last pop-III stars were thought to have burned out. Sobral thinks we must be witnessing a pocket of late bloomers. He favours the idea that pop-III stars did not blaze on in synchrony across galaxy CR7, but rather lit up in waves. Some metal-containing pop-II stars in the galaxy are older than CR7's cluster of pop-III stars, which supports this idea.

THESE EARLY STARS COULD GROW TO AN EXTRAORDINARY SIZE. A POP-III STAR WOULD BLAZE WITH THE BRIGHTNESS OF A MILLION SUNS.

"It's pretty spectacular that they have evidence that's leaning towards that theory," says Bauer. The only other explanation for Sobral's observation could be that a black hole collapsed immediately from a gas cloud without first forming a star – an object itself only theorised and never seen.

Radiation from the feeding black hole could be lighting up CR7. Such a discovery would be equally as exciting, Bauer adds, as it could help explain the origin of the supermassive black holes scientists now believe lurk at the centre of every galaxy.

Getting a definitive answer will require a deeper look with Hubble, and by its successor, the James Webb Space Telescope, to be launched by NASA in 2018.



An artist's impression of CR7, a very distant galaxy three times brighter than any other known galaxy from this period.

CREDIT: ESO / M. KORNMESSER

PHYSICS

Time travel and the single atom

Researchers have confirmed one of the most profound thought experiments of quantum physics. CATHAL O'CONNELL explains.

We all have times we wish we could go back in time and make a different decision. Now that appears to be possible – for single atoms, at least. Physicists at the Australian National University have confirmed one of the most profound thought experiments of quantum physics. It appears to show that present actions can affect past events.

Andrew Truscott and his team showed that if you offer a speeding helium atom two possible paths, the route it takes appears to be determined by how the researcher measures the atom at the end of its journey. This phenomenon holds even if the researcher makes the choice after the atom has departed. The team reported the strange discovery in *Nature Physics* in May.

"It's a fantastic experimental tour de force," says Radu Ionicioiu, a physicist at Bucharest's Horia Hulubei National Institute for Physics and Nuclear Engineering. "But how to interpret it? If you ask 10 people, you'll get 11 opinions."

Atoms are governed by the strange laws of quantum mechanics. We have long known these laws give quantum particles a split personality. Take photons, perhaps the most studied quantum particle. Sometimes a photon will behave like a particle, bouncing like a pebble off a wall. But photons can also behave like waves, rippling as they pass between narrow gaps. Weirdly, the observer appears to determine the characteristics the photon adopts. Test it for waviness and it will behave like a wave; look for particle-like behaviour, and that's how it will manifest.

Ionicioiu sums up the paradox: "The question is, how can the same thing behave both ways, depending on what sort of question you ask?"

In the late 1970s John Wheeler, one of the giants of 20th century physics, was pondering this question of split personality when he realised quantum behaviour implied an even weirder possibility – that an observer's influence on a photon's behaviour could travel back in time.

In Wheeler's "delayed-choice" thought experiment a photon is presented with a "choice" – to act as a particle or as a wave. The photon is then measured a bit later to find out what choice was made. In 1978 Wheeler proposed a way to test the idea in the lab: send a photon towards a crossroads (in this case a half-silvered mirror – see diagram). Wheeler realised that if the experimenter then recombined the two pathways (using a second mirror) at a point further along the track, then the photon should act like a wave. When a wave of water strikes a forked channel it splits into two and ripples down both paths at once. The photon should do the same. But if the experimenter does *not* recombine the paths, then the photon should act like a solid particle, bouncing down one of the paths.

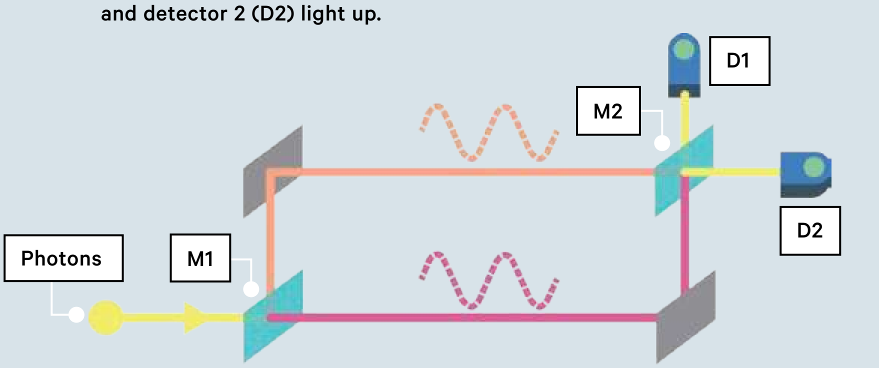
Performing Wheeler's experiment seemed almost impossible at first, as it required rejigging mirrors while the speeding photon was in mid-flight.

HOW IT WORKS

Firing a photon at half-silvered mirror 1, which a photon has a 50:50 chance of reflecting off or passing straight through, presents it with a choice: behave like a wave and ripple down both pathways at once (A) or behave like a particle and travel down one of the two possible pathways (B).

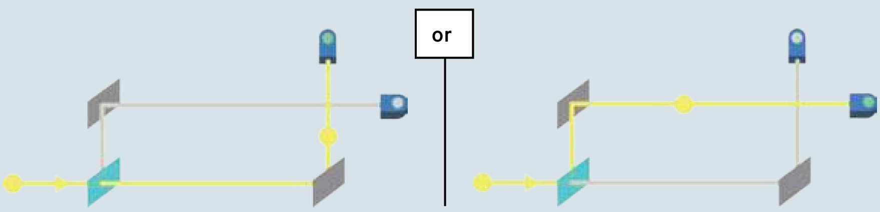
A

Only after the photon has passed mirror 1 (M1), do the scientists decide whether to insert mirror 2 (M2). Inserting the mirror recombines the two pathways, and the scientists detect wave-like behaviour – detector 1 (D1) and detector 2 (D2) light up.



B

Leave mirror 2 out, and the scientists detect particle-like behaviour – detector 1 or detector 2 lights up.



The experiment seems to show that a decision the scientists make after the photon passes mirror 1, retrospectively controls what that photon did at mirror 1.

A version of the experiment was finally achieved in 2007 when a French team built a 48-metre-long path for their light beam, which allowed just enough time for the equipment to be switched around after the photon passed the mirror crossroads, but before it reached the detectors.

Physicists have now taken the experiment to a different level. They have shown that Wheeler's time experiment works not only with ephemeral photons of light, but also with matter in the form of single atoms. It has long been known that single atoms can also display wave-particle duality.

To carry out their experiment, Truscott and his team collected about a thousand helium atoms in a laser 'cup', and cooled them to one billionth of a degree above absolute zero.

The crowded atoms bumped and jostled, knocking each other out of the laser trap, until eventually a single atom remained. The team then allowed the atom to fall towards crisscrossing laser beams. The lasers split the atom's trajectory into two possible paths. After the atom passed the crossroads, the equipment randomly switched to a set-up that either recombined the two possible paths, or did not.

THE BIG LESSON FROM THE EXPERIMENT IS THAT WE CAN'T APPLY CONVENTIONAL INTUITION TO QUANTUM SYSTEMS.

The atom behaved in the same way as the photon. If the paths were recombined this produced an interference pattern typical of a wave, showing the atom travelled down two paths at once. If the paths were not recombined, the atom banged into one of the detectors at the end of each track, in the same way a pebble would.

For Truscott, the big lesson from the experiment is that we can't apply conventional intuition to quantum systems – they do not recognise human ideas such as "the past". "The experiment says that there are some things, such as the path followed by a particle, that you just cannot know," he says. You can only talk about the *probability* that the particle is in a particular place at a particular time, he says.

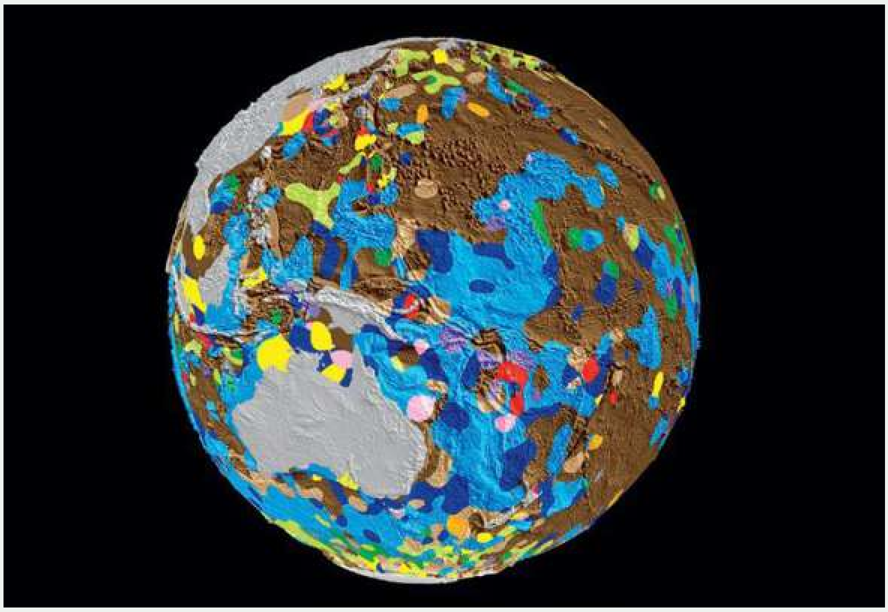
Joan Vaccaro, a quantum physicist at Griffith University, says much of the confusion arises because people insist on describing quantum objects as either particles *or* waves. She suggests resurrecting British physicist Sir Arthur Eddington's 90-year-old idea: "He coined this term 'wavicle' to give quantum systems a different name, instead of referring to them as either a particle or wave, when it shouldn't be either."

For Ionicioiu, studying quantum mechanics is like entering another world, "one with different rules".

He quotes Richard Feynman, a PhD student of Wheeler's, who said in his *Lectures on Physics*: "The 'paradox' is only a conflict between reality and your feeling of what reality ought to be."

CAPTURED

THE OCEAN'S SECRETS



Australian scientists have created the first digital map of the ocean floor's composition. The last hand-drawn map of this type was made in the 1970s. "In order to understand environmental change in the oceans we need to better understand what is preserved in the geological record in the sea bed," says lead researcher Adrianna Dutkiewicz from the University of Sydney. Published in the August edition of *Geology*, the map reveals the deep ocean basins are more complex than previously believed.

"The deep ocean floor is a graveyard with much of it made up of the remains of microscopic sea creatures called phytoplankton which thrive in sunlit surface waters," says Dutkiewicz. "The composition of these remains can help decipher how oceans have responded in the past to climate change."

For instance a special group of phytoplankton called diatoms produce about a quarter of the oxygen we breathe. The new map show diatom accumulations on the sea floor are nearly entirely independent of diatom blooms in the Southern Ocean. More research is needed to better understand the relationship (see Lab Talk, *Another reason to save the whales*, page 25).

CREDIT: EARTHBYTE GROUP, SCHOOL OF GEOSCIENCES, UNIVERSITY OF SYDNEY

LIFE SCIENCES

The brain's surprising lymphatic drain

A startling anatomical discovery could inspire new treatments for Alzheimer's and other neurological diseases. VIVIANE RICHTER reports.

Has the human brain been hiding a dirty secret? While studying the membranes around a mouse brain, neuroscientist Antoine Louveau stumbled across something that wasn't supposed to be there: a web of drainage channels called lymphatic vessels.

Medical students have long been taught the mammalian brain is cut off from the lymphatic system which helps protect the body from infection. Louveau's discovery will force a rewrite of anatomy textbooks and could change how we treat neurological diseases such as Alzheimer's and multiple sclerosis.

Along with Jonathan Kipnis and colleagues at the University of Virginia, Louveau published his discovery in *Nature* in June. "This research opens up a whole bunch of possibilities," says Ben Hogan, geneticist at the University of Queensland.

Two major plumbing systems run through your body. Blood vessels carry nutrients and oxygen to the tissues. Lymphatic vessels drain tissue waste but also play another crucial role: they are a major conduit for the immune army.

When you cut your finger, sentry immune cells, including T cells, travel through the lymphatic vessels to the immune army's headquarters known as the lymph nodes. Here the sentries sound the alarm that bacteria have entered the cut. They recruit more T cells which are educated about the precise bacterial target before being released into the blood to hunt down invaders.

The brain, being cut off from the lymphatic system, was thought to rely on a home-grown army of protective cells known as microglia. But researchers have long puzzled over how the brain could mount a more strategic defence. "How do you get a precise immune response without lymphatic drainage?" wondered Kipnis.

Then last year, Louveau found himself looking at lymphatic vessels in mouse meninges – the membranes surrounding the brain.

"We thought holy moly!" says Kipnis. "This must be wrong, or it's published and we somehow overlooked it, or we just discovered something cool."

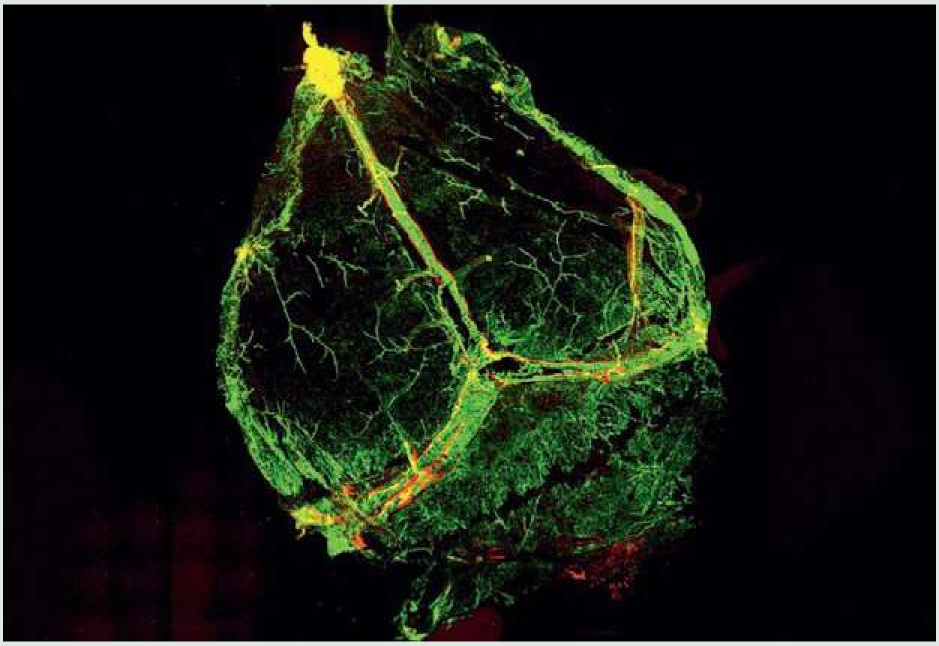
Louveau was using a new method to dissect the mouse brain that involved stabilising the meninges with a chemical before stripping them from the skullcap. Once he had the intact meninges in hand he took a fresh look at their lymphatic vessels. They were supposed to stop at the skull's base. Not so. They continued up into the brain and ran alongside the blood vessels – probably the reason they had been so well hidden. His team were also able to show these lymphatic vessels carried immune cells.

The researchers think they have also found similar lymphatic structures in human brain meninges. And that opens up new ways of thinking about human brain disease. Kipnis suspects the lymphatics may play a role in Alzheimer's disease or multiple sclerosis. His team is now looking into how the vessels differ in the brains of patients without brain diseases.

"WE THOUGHT HOLY MOLY! THIS MUST BE WRONG, OR IT'S PUBLISHED AND WE SOMEHOW OVERLOOKED IT, OR WE JUST DISCOVERED SOMETHING COOL."

It may also be possible to tinker with the drainage system to treat disease. For instance the gluggy deposits called amyloid are implicated in Alzheimer's disease. Perhaps boosting the brain's lymphatic drainage could help clear them away? On the other hand, multiple sclerosis is a result of T cells running rampant in the brain. In that case it might be helpful to restrict access via the lymphatic system.

Hogan is excited but remains cautious. "We now need to start with the very basics," he says.



Just like the rest of the body, the brain has a lymphatic drainage system. It has only now been detected. In this mouse brain image, lymphatic vessels (red) are shown alongside the blood vessels (green).

CREDIT: ANTOINE LOUVEAU

We ask researchers to tell us about their discoveries and to explain why they matter.

LAB TALK

DAVID FARMER is a neurophysiologist at Melbourne's Florey Institute of Neuroscience and Mental Health.

'When a brainstem sees a bear …'

The brainstem is one of the oldest structures in the brain. It is not concerned with the grand mysteries of consciousness, emotion or identity: the brainstem handles life support.

One particular group of cells in the brainstem is responsible for driving the breathing muscles. These cells work together to produce the rhythmic muscle movements that draw air into your lungs.

This rhythmic breathing pattern is essential for survival. But, sometimes, producing other patterns of activity in these same muscles can be useful.

For example, if you see a bear, or any other large, alarming stimulus, it might help your chances of survival to breathe more heavily or quickly to get ready to fight or run away (if it is a bear I strongly recommend the latter).

If the stimulus is particularly scary then you might shout involuntarily. Or you might hold your breath. All these responses are patterns of activity in your breathing muscles that are generated by your brain.

How these patterns are generated fascinates me.

One way these patterns can come about is that 'higher' (that is, more complex or more recently evolved) brain structures can talk to the brainstem and hijack the breathing muscles.

Recently, we looked at how the breathing pattern was changed by stimulating the midbrain in rats. We did this using a new experimental technique, physically isolating the midbrain and brainstem from the rest of the brain.

When we activated the midbrain (with tiny injections of neurotransmitter) we found we could produce a range of different breathing patterns in the brainstem. These included heavy breathing (such as might occur during exercise) and rapid breathing (resembling sniffing).

So we now have a new tool to learn about the brainstem and how we get our respiratory muscles to perform functions other than breathing.

Think about that the next time you meet a bear!

PAPER: The midbrain periaqueductal grey has no role in the generation of the respiratory motor pattern, but provides command function for the modulation of respiratory activity, *Respir Physiol Neurobiol*, 2014, vol 204, p14–20.

LAVENIA RATNARAJAH is a marine biogeochemist at the University of Tasmania.

Another reason to save the whales

Commercial whaling has killed off nearly 1.3 million whales, including blue, fin and humpbacks since the early 1900s. This calamity has disturbed the ocean's iron cycle with knock-on effects for us.

The cycle starts with phytoplankton, single-celled algae that take up carbon dioxide from the atmosphere and produce oxygen during photosynthesis.

Marine phytoplankton can produce more than 50% of the air's oxygen. In essence, every second breath you take comes from marine phytoplankton.

Iron is essential for the photosynthetic machinery in phytoplankton. But large areas of the Southern Ocean are iron deficient. And this is where whales come in – they recycle iron.

Phytoplankton take up iron from seawater and are eaten by small, abundant crustaceans called krill. (Uneaten phytoplankton sink to the bottom of the ocean when they die, taking their carbon and iron with them.) The krill are devoured by baleen whales, a family that includes blue, fin and humpback whales.

During the Southern Ocean's summer feeding season, an adult blue whale eats up to two tonnes of iron-rich krill per day. Fully grown adults don't need much unless they are pregnant or injured – they defecate the unwanted iron they consume. The fluid-like faeces rise to the surface and disperse, providing fertiliser to the sun-drenched surface waters.

We at the University of Tasmania have found baleen whales recycle large amounts of iron. More than 10 million times more iron is concentrated in their faeces than in seawater.

Whales were once important to the Southern Ocean's iron cycle; their demise may have led to a less productive sea.

Allowing whale populations to recover would boost the amount of iron in seawater as more krill are turned into liquid fertiliser.

This would lead to more phytoplankton growth, which could suck up more atmospheric carbon dioxide.

And that's good for everyone.

PAPER: The biogeochemical role of baleen whales and krill in Southern Ocean nutrient cycling, *PLOS ONE*, 2014, vol 9, e114067.

TECHNOPHILE

To sail the heavenly breeze

A solar sail uses photons from the Sun to propel its flight in space. By CATHAL O'CONNELL.

"Provide ships or sails adapted to the heavenly breezes, and there will be some who will brave even that void."
— Kepler in a letter to Galileo, 1610.

Arthur C. Clarke's 1964 story *Sunjammer* describes a race between space yachts sailing the Solar System propelled by sunlight. LightSail is the latest and most compact realisation of this fantasy.

A black box about the size of a loaf of bread, LightSail is a most unlikely looking space yacht. Yet it could potentially cross the heavens faster than any rocket.

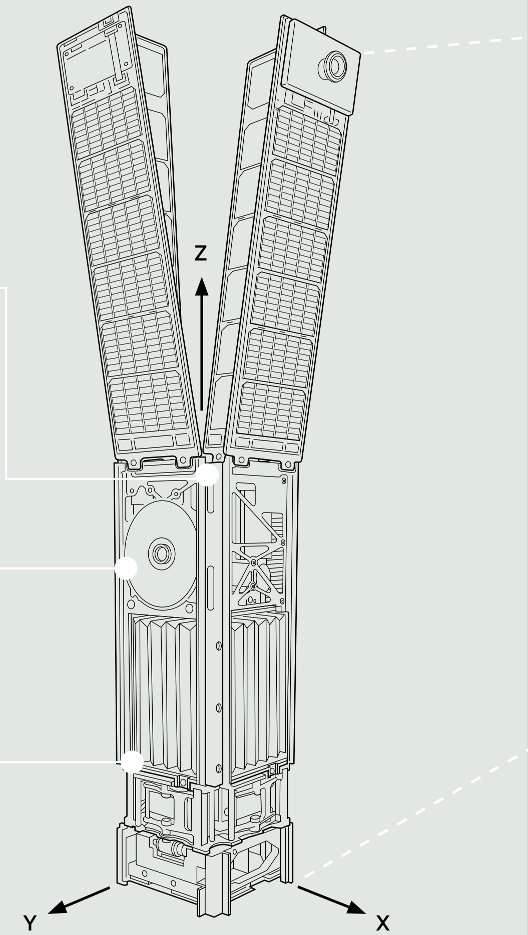
Last June, floating free in low-Earth orbit, its four doors opened like petals, a spindly arm emerging from each. Then, like a magician conjuring handkerchiefs from a pocket, the arms unfurled a shiny, metallic sheet that grew and grew, until it flattened into a sail angled towards the Sun. Light yachts sail because particles of light (photons) have momentum. When they bounce off a reflective surface they give it a tiny kick. With enough photons, the tiny kicks add up to a significant thrust. A spacecraft with a large enough sail could eventually reach incredible speeds with zero fuel. Harnessing sunlight could allow us to send faster and cheaper probes to the outer Solar System.

Solar sailing projects have been mooted by space agencies since the 1970s (including a plan by NASA to sail to Halley's Comet in 1986). But it wasn't until 21 May, 2010 that the first space yacht – the Japan Aerospace Exploration Agency's IKAROS (Interplanetary Kite-craft Accelerated by Radiation Of the Sun) – was launched into orbit. When its 196-square-metre sail opened to catch the solar breeze, IKAROS became the first craft to use photons as its main form of propulsion. It reached Venus in a little more than six months, completing its flyby on 8 December, 2010. IKAROS is now in a stable seven-year orbit around the Sun between Venus and Mercury.

Solar sailing has also captured the attention of amateurs interested in a relatively cheap way of exploring space, which is how LightSail came into being.

Whereas IKAROS cost about $20 million to build and launch, LightSail is being run on a $1.5 million budget, raised by public donations to a Kickstarter campaign. The project is driven by The Planetary Society, a non-profit co-founded by Carl Sagan in the early 1980s to promote space exploration.

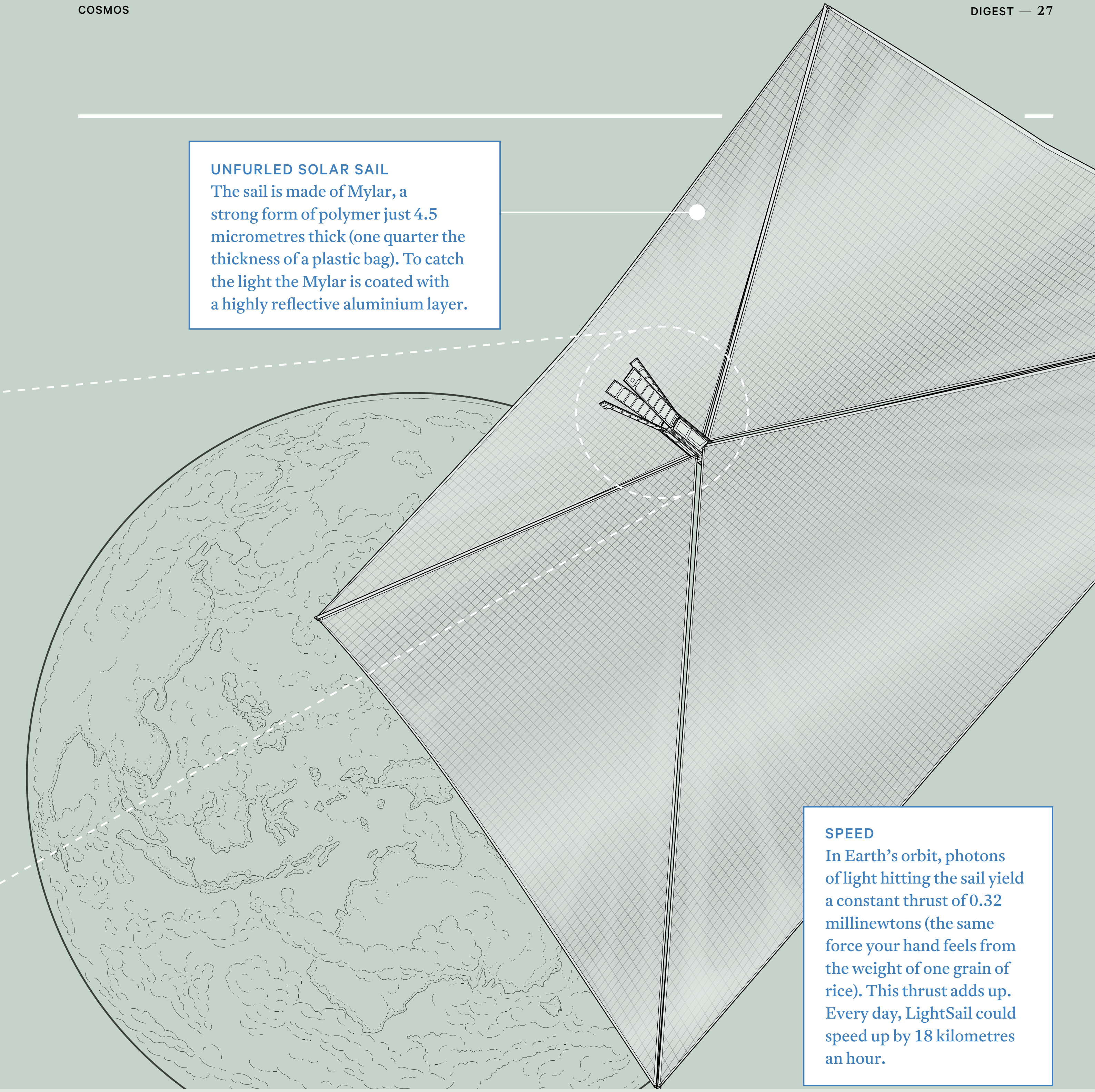
To keep costs low, LightSail is designed as a CubeSat, meaning it's small and light enough to hitch a ride into space. When



TORQUE RODS
LightSail is steered by angling the sail in relation to the Sun. When the craft is within Earth orbit, controllers can angle LightSail with three electromagnetic torque rods – electromagnets on sticks, tucked within the craft – one oriented along the craft's X axis, one along the Y and one along the Z. Increasing a rod's magnetic field strength causes it to push on the Earth's magnetic field and makes the craft tilt.

MOMENTUM WHEEL
By spinning this electrically powered flywheel, controllers can fine-tune the spacecraft's orientation in space.

STOWED SOLAR SAIL
When folded, the 32 square metre sail and the extendable booms that deploy it pack into a 10 x 10 x 20 centimetre space.



a large satellite is launched into orbit, for instance, CubeSats can be tucked into a corner of a launch rocket without inconveniencing the main cargo.

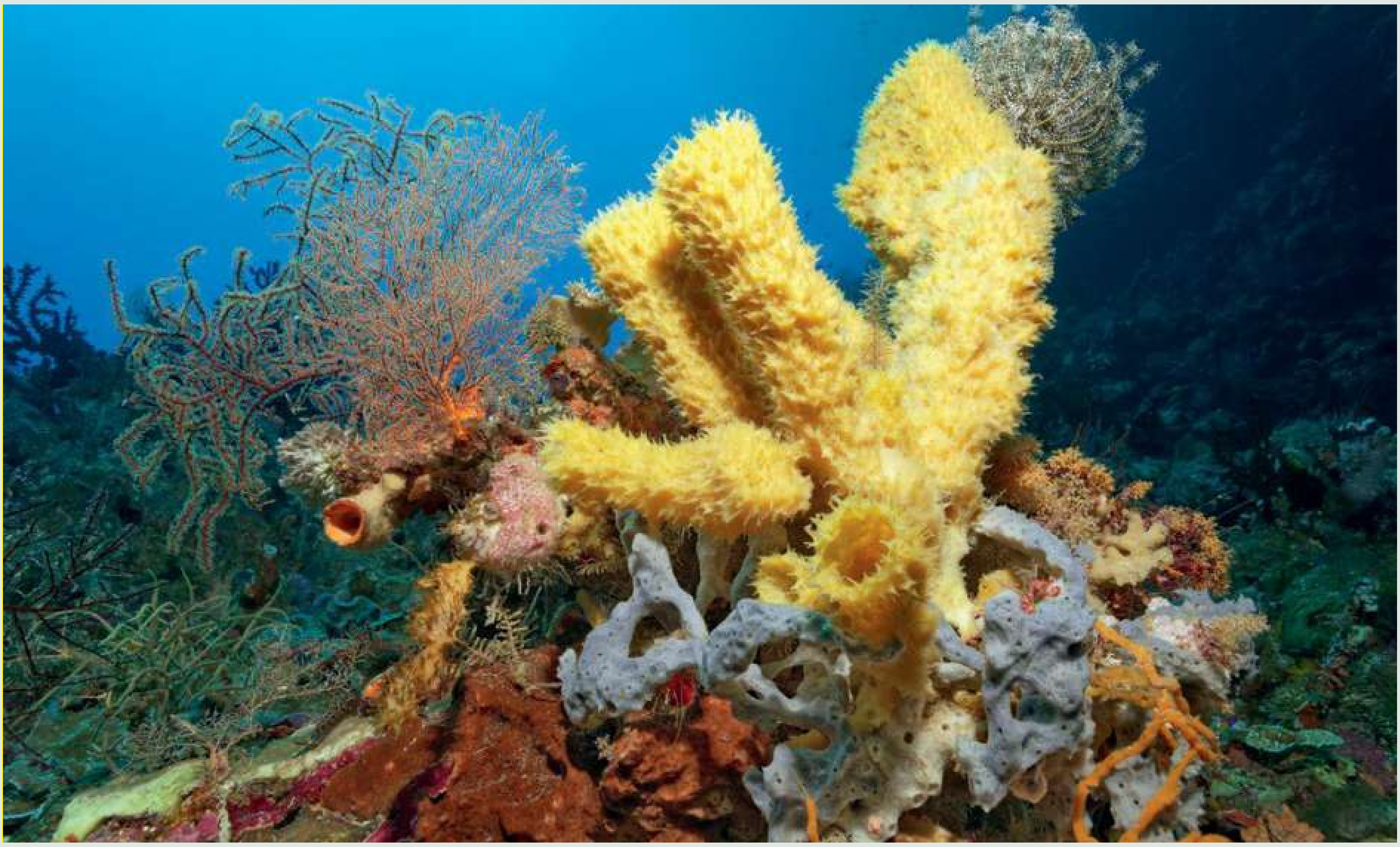
LightSail boxes weigh in at five kilograms and are only 30 centimetres long – you could squeeze two in your carry-on luggage. But once unfurled, LightSail's microscopically thin aluminium-coated polymer sail covers 32 square metres. Besides the sail and motors, LightSail is packed with a two-way radio, a control system and onboard imaging cameras. "You can package a very large sail into a tiny little spacecraft, and you can do something useful with it," says Jason Davis from the Planetary Society.

For the June experiment, the LightSail craft hitched a ride on an Atlas V rocket. It was dropped off in a low-Earth orbit and the arms unfurled the sails. "The deployment was perfect, " says Bill Nye, chief of the Planetary Society. However, at that altitude the drag of the upper atmosphere gradually slowed it down. It fell back to Earth after about a week.

The successful demonstration paves the way for a device to hitch another launch ride in 2016. This time the sails will unfurl at an altitude of 720 kilometres – conditions ripe for fair-weather sailing.

ILLUSTRATION: ANTHONY CALVERT

CLIMATE WATCH



The diverse corals on Australia's Great Barrier Reef are endangered by climate change. Scientists are hoping to help corals evolve to thrive in a warmer environment. CREDIT: NORBERT PROBST / IMAGEBROKER / CORBIS

LIFE SCIENCES

Can corals survive in warmer seas?

Some corals are better adapted than others to live through a heat wave. Scientists wanting to save coral reefs are taking note. BELINDA SMITH reports.

Australia's Great Barrier Reef narrowly missed getting an "in danger" listing from UNESCO in May. But clamping down on coastal development and cleaning up the water may not be enough to make the world's largest coral reef safe.

If the climate warms by 2°C it will threaten many of the more than 400 species of coral that live on the reef, and could shrink the world's reefs by two thirds, according to a 2013 *Nature Climate Change* paper.

Corals have adapted to huge climatic changes over the millennia, but it is not known if they can adapt to similar changes over decades. If corals can't adapt quickly enough on their own, could science help?

Most reef-building corals are part animal (polyp) and part plant (zooxanthellae) – a symbiotic marriage born of the need to survive in nutrient-poor tropical waters. The polyps are related to sea anemones. Tiny translucent sacs, they have a limestone base that attaches them to rocks (or each other) and a tentacle-covered mouth to snag prey. They share their waste nitrogen and phosphorus with their zooxanthellae partners and build complex structures that allow the algae-like zooxanthellae to access light. In exchange, the zooxanthellae share the sugars they make via photosynthesis.

The coral marriage can cope with short, sharp blasts of heat during a hot summer spell. But when the temperature rise is sustained – even by less than a degree – the coral's stress levels erupt. Sadly, the zooxanthellae and polyps then part ways, leaving the coral ghostly white. It's called coral bleaching.

Scientists don't entirely understand why coral responds so drastically. One theory is that heat and bright light makes zooxanthellae hyperactive.

With photosynthesis in overdrive, the excess energy is released as protons. These generate free radicals that could poison the polyps.

Losing their zooxanthellae partners is not an automatic death sentence for corals. When the weather cools corals can grow new plant partners from algal remnants.

Coral polyps die when bleaching events are too sustained or frequent. For instance, reefs across the Pacific and Indian Oceans, the Caribbean and the Red Sea were bleached during an El Nino event in 1997/98. Some 16% of the world's coral died.

The Intergovernmental Panel for Climate Change predicts sea temperatures will rise by between 1°C and 4°C by 2100 – bad news for reefs.

Can corals adapt in less than 100 years? The Great Barrier Reef's saving grace may lie in its vast size – measuring about 2,300 kilometers from north to south, it is about the same length as Italy. Its northerly corals are already adapted to hotter waters. A paper in *Science* in June suggested scientists could help cool water corals learn some lessons from their hot water cousins.

Princess Charlotte Bay is almost 350 kilometres north of Cairns, with sea temperatures 2°C higher than the main stretch of reef. Here the branching coral species *Acropora millepora* thrives thanks to adaptations evolved by its polyps. Could their genes also help more southern corals?

A team co-led by coral researcher Line Bay from the Australian Institute of Marine Science in Townsville, and Mikhail Matz at the University of Texas at Austin, tested that idea. The team crossed the northerner with the same species living 540 kilometres further south at Orpheus Island.

The offspring were 10 times more resistant to heat stress than their sensitive southern parents. Many of the heat tolerance genes bequeathed by the northern polyps appeared to come from the mitochondria, the organelles responsible for energy production. Matz and Bay suspect these mitochondrial genes might help polyps resist free radical stress induced by overheating – something they plan to explore next.

The study is the first to show heat tolerance can be inherited. "It opens up possibilities for rapid evolution," says Bay. Matz suggests this is likely to happen naturally as the northern larvae can disperse over vast distances. But the process "can be jump-started by humans moving adult corals", he says.

And it's not only polyps that have evolved to cope with the heat. University of Southampton biological oceanographer Jörg Wiedenmann studied corals living in the Persian Gulf, where water temperatures regularly reach 35 °C – and found a new type of zooxanthella that could take the extreme heat. He and colleagues published their new species, *Symbiodinium thermophilum*, in a February issue of *Scientific Reports*. But the corals' exceptional heat tolerance was strongly coupled to their ability to survive the Gulf's high salinity. Taken out of super salty seawater, they died.

So moving coral colonies and their zooxanthellae is not likely to be a panacea. Bay says: "Assisted colonisation has been suggested before. But we're not yet at the stage where we can say 'yep, we're ready to go, there's no problem with this'."

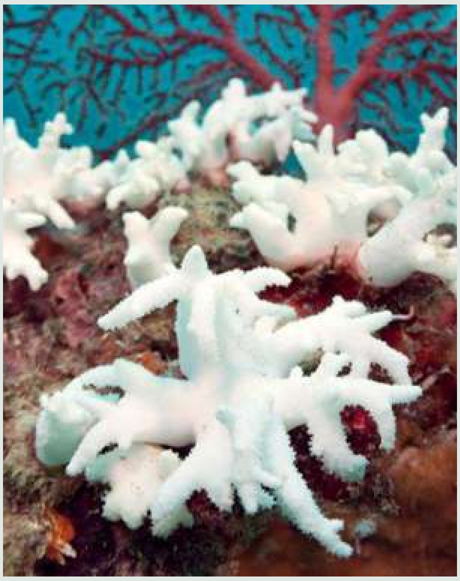
Ultimately, whether they relocate naturally or with help, there's a limit to how far corals can move from the equator, adds Queensland Museum coral researcher Paul Muir in Townsville.

In a paper published in *Science* in June he and colleagues analysed coral depth distributions and found that they are limited by winter sunlight. The sunlight at higher latitudes is too weak for zooxanthellae to photosynthesise, because not enough light penetrates to the depths where the corals grow. Moving coral to shallower water wouldn't help, he adds. Not all corals can survive exposure at low tide – waves and swells tend to shatter their delicate skeletons.

As oceans warm, corals will need to adapt to multiple pressures. More acidic oceans – caused by dissolved carbon dioxide – and higher temperatures tend to go hand in hand, Bay says. She plans to see if heat-tolerant corals such as those in Princess Charlotte Bay can also cope with more acidic seas.

But breeding strategies and relocating corals are unlikely to help corals adapt quickly enough. Wiedenmann, Bay and Muir say that aside from limiting our CO_2 emissions, the most important help we can give the corals is to keep their existing homes pristine by reducing fertiliser run-off from creeks and not dredging the sea floor. These activities trigger algal blooms and make the waters murky, depriving zooxanthellae of sunlight.

Australia has agreed to do that. UNESCO will be back in 2017 to check we have kept our promise.



Bleached corals in Cenderawasih Bay, West Papua, were damaged by a heat wave.

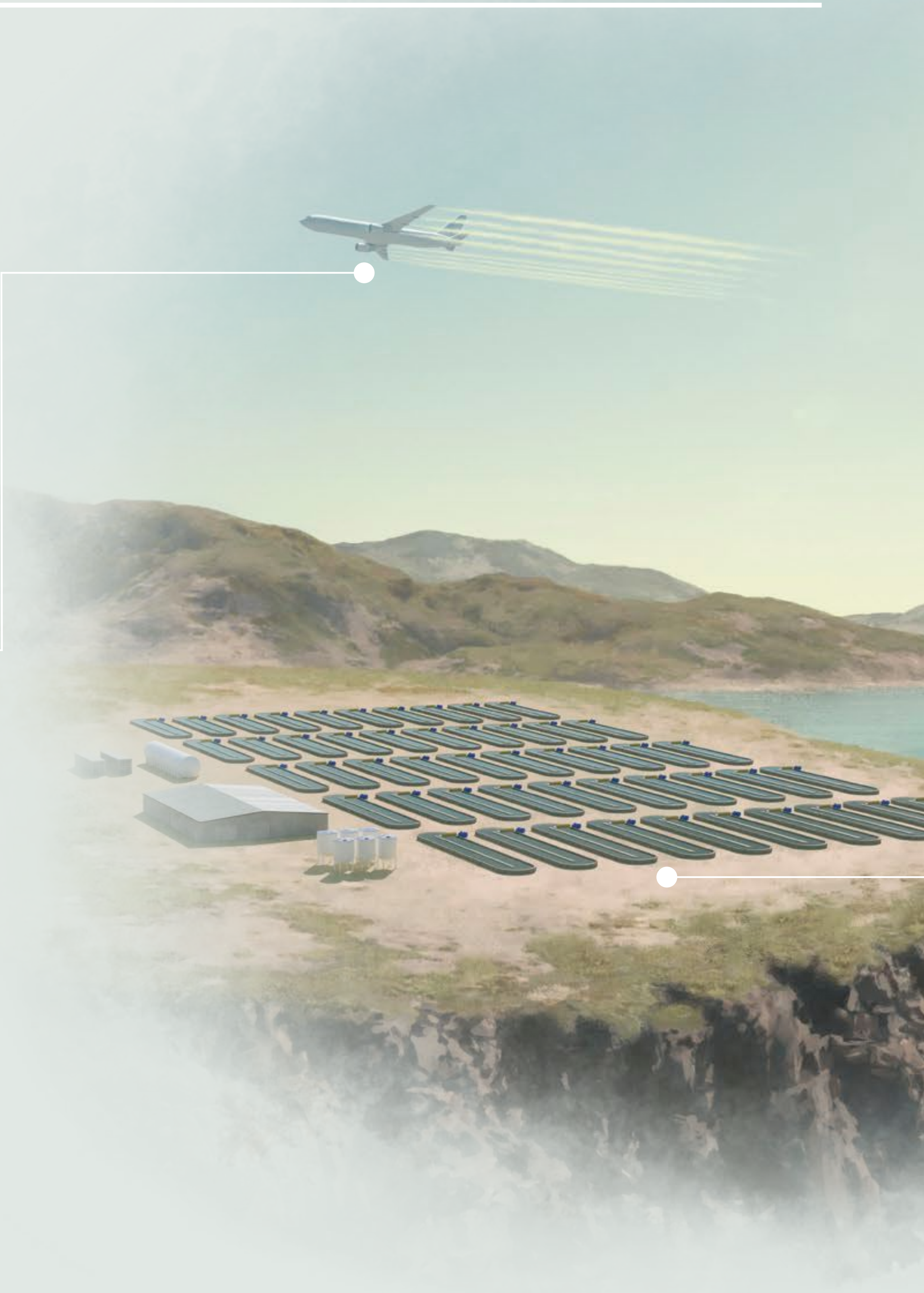
CREDIT: REINHARD DIRSCHERL / GETTY IMAGES

These polyps can thrive in hot, salty seawater thanks to their algal partners.

CREDIT: D'ANGELO / WIEDENMANN / BURT

IN FOCUS

ENGINEERING THE CLIMATE
It’s probably too late to stop our planet warming more than 2°C – even if the November UN climate conference achieves a 90% reduction in emissions. Geoengineering is plan B. It involves blocking sunlight or scrubbing CO_2 from the atmosphere. But there’s a risk we could flip the climate in unintended ways. Some say we should test geoengineering before we reach the point of crisis. “Geoengineering is a horrifying concept, but we need to get beyond the shock and awe,” says CSIRO oceanographer Andrew Lenton.

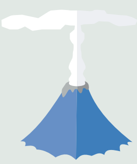


1

SULFATE AEROSOLS

Mimicking volcanic eruptions, planes could spray sulfuric acid into the stratosphere, creating a reflective haze. The strategy is favoured by Harvard University’s David Keith. But the haze could destroy the ozone layer.

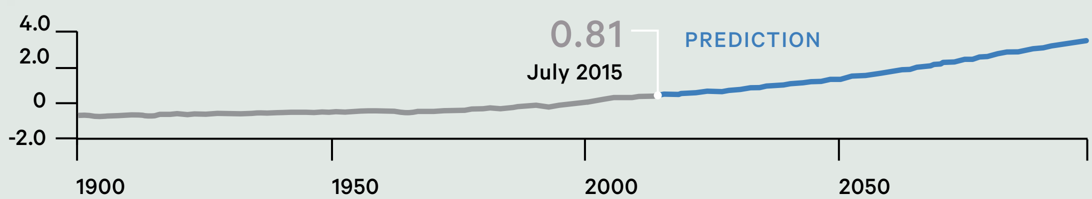
EFFECTIVENESS: ●●●●○
DANGER: ●●●○○
COST: ●●○○○



The 1991 Philippines’ Mount Pinatubo eruption blasted 20 million tonnes of sulfur dioxide and ash into the stratosphere, blocking out enough sunlight to plunge global temperatures by 0.5°C for two years.

BUSINESS AS USUAL

GLOBAL SURFACE WARMING (°C)



SOURCE: IPCC / NOAA

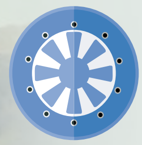
Compiled by Viviane Richter

2

CLOUD BRIGHTENING

Clouds could be made more reflective by impregnating them with salt. Silicon Valley scientists are designing equipment that could be carried aboard ships to loft a fine spray of sea water into Earth's lower atmosphere. But could tampering with clouds trigger floods or droughts?

EFFECTIVENESS: ●●●●○
DANGER: ●●○○○
COST: ●●●○○



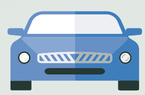
Specially designed nozzles produce 60 to 100 nanometre salt particles needed to brighten clouds.

3

ALGAE

Algae are the ideal sponge to reabsorb CO_2 from the atmosphere, believes Richard Sayre at Los Alamos National Laboratory. Growing, harvesting and burying them is expensive, but super-fast-growing *Chlorella sorokiniana* are cheaper to grow. Effects will not be immediate but might be part of a low-risk, long-term solution.

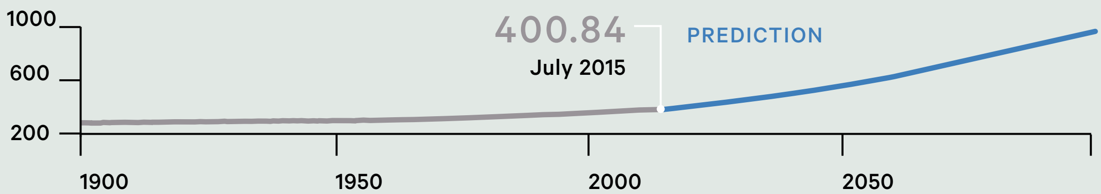
EFFECTIVENESS: ●●○○○
DANGER: ○○○○○
COST: ●●●●○



An algal pond the size of an Olympic swimming pool could offset CO_2 produced by five cars per day.

ILLUSTRATION: TOM SIMPSON / JACKY WINTER GROUP

ATMOSPHERIC CO_2 CONCENTRATION (PPM)



SOURCE: IPCC / NOAA




OPINIONS, IDEAS & PERSPECTIVES

VIEWPOINT

"WE FEEL UNCOMFORTABLE ABOUT BEING ALONE IN THE UNIVERSE"

ALAN FINKEL — ENGINEERING

NORMAN SWAN
BODY TALK

KATIE MACK
ASTRO KATIE

LAURIE ZOLOTH
PHILOSOPHER'S CORNER

ALAN FINKEL
INCURABLE ENGINEER

NORMAN SWAN is a doctor and multi-award winning producer and broadcaster on health issues.

BODY TALK

Falling through the gender gap

How personal can medicine get?

THE 21st CENTURY is all about personalised medicine. Have genome; have custom-made treatments.

All very well, but there's a glaring omission – if you're a woman.

From mice to humans, the subjects of medical research are mostly male. A 2010 *Nature* editorial "Putting Gender on the Agenda" estimated the ratio of male to female experimental animals in neuroscience is an astounding 5.5 to one. True: with clinical trials, crude analysis of the participation rates sometimes shows that women outnumber men, but when you remove trials on female-specific conditions, male dominance reappears.

The critics argue that there's a problem from beginning to end. Animal research that tests new drugs before they go into humans is biased toward males.

Then in early stage human trials, that determine safety and dosage, male-female differences are ignored. Furthermore, because we have invested so little in post-marketing surveillance – in which new drugs are monitored after going on the market – female-specific complications or treatment failures are only detected by chance.

Some researchers say the result is a long list of treatments prescribed for women with little or no evidence of what doses work best, whether the safety profile is the same, or even if they are effective.

There are good reasons to think women do not respond to medical treatments the way men do. For starters, they do not have the same set of genes. Men have genes specific to the Y chromosome and women get a double dose of the genes on their X. And even the genes that are identical can operate differently through what are called epigenetic effects – in which experience alters how genes behave. Clearly the experience of being a woman is different to that of being a man.

One obvious factor is the sex hormones. Oestrogen, progesterone and testosterone all influence how the metabolism works, for instance how drugs are broken down in the liver. That means the rate at which drugs are cleared from the bloodstream – and hence their functional doses – can differ between the sexes.

Occasionally, problems emerge. A recent example was a sleeping pill called Zolpidem or Stilnox, which women eliminate more slowly than men. That led to cases of women with impaired alertness the morning after taking the pill and "sleep-driving" with disastrous effects.

In 2013, the US Food and Drug Administration called for a 50% reduction in bedtime doses of the drug, especially in women.

Why do researchers use more males than females?

Fundamentally because the female of the species is more complex. Her body changes as she ovulates, menstruates or becomes pregnant. To sort out these influences in a drug study would require more subjects and longer durations, making the process much more expensive.

In addition, researchers may be nervous that a woman will become pregnant during a drug trial and expose her foetus to unknown risks.

Women also live longer and develop heart disease more slowly, which means that testing a new heart drug will also incur a larger sample size and cost.

And then there's the difficulty of recruiting enough women. Because women are more likely to be carers, they may be less likely to have time to participate in a trial. Some of these reasons are real, some imagined, but they all strengthen the argument for more female representation. If the research results are more trustworthy, the extra cost may be worth it.

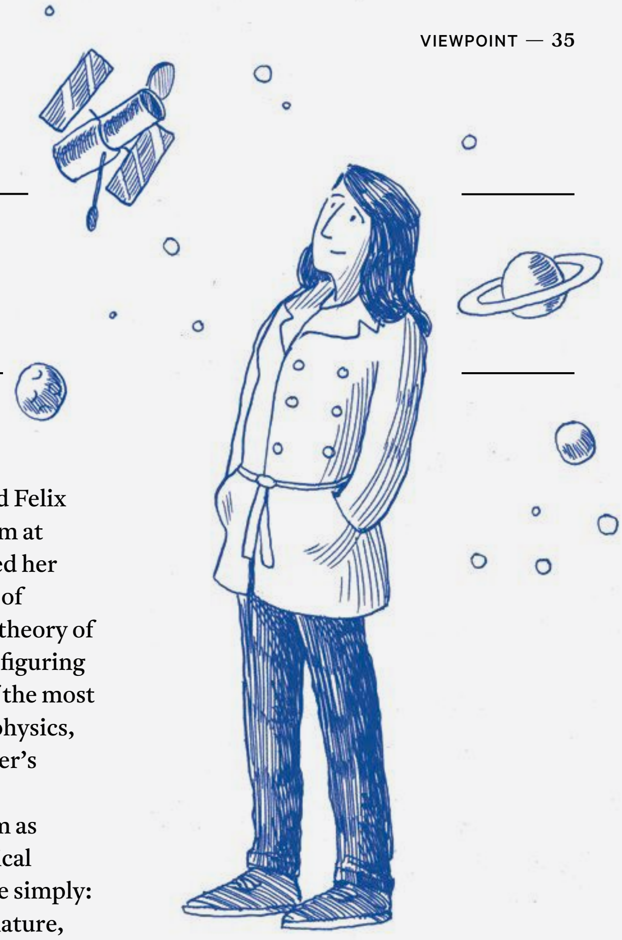
A LONG LIST OF TREATMENTS ARE PRESCRIBED FOR WOMEN WITH LITTLE EVIDENCE OF WHAT WORKS BEST.

It's not a new issue. For many years agencies in the US have tried to ensure better female participation in drug trials – with limited success. Changing research practices isn't easy but solutions include: that funding bodies insist on gender balance; greater awareness of the issue on ethics committees; and drug regulators asking for gender-specific data.

Women would do well to take matters into their own hands. The next time they visit a doctor they might consider asking whether the drug they are being prescribed has been adequately tested in women. This should give a powerful impetus for change.

KATIE MACK is a theoretical astrophysicist who focuses on finding new ways to learn about the early Universe and fundamental physics.

ASTRO KATIE



A harmonious mind in an unequal equation

Mathematician Emmy Noether was a genius who laid the basis for a new approach to physics.

NOETHER'S THEOREM is to theoretical physics what natural selection is to biology. If you wrote an equation encapsulating all we know about theoretical physics you could label terms contributed by Feynman, Schrödinger, Maxwell and Dirac, but if you wrote "Noether" on the equation it would have to cover the entire thing.

Emmy Noether was born in Bavaria in 1882. Despite attending finishing school and being certified to teach English and French, she found the mathematics her father and brother were doing at Erlangen University interested her more. Women weren't allowed to enrol, so she aced the entrance exam and audited classes until Erlangen finally admitted women and she could get her PhD.

Noether went into research and more or less *invented* the field of abstract algebra. The core of the discipline is to examine the structure of mathematics and reduce it to its most abstract form. Noether's goal was to find out how mathematical ideas relate to each other and construct general mathematical structures. She never claimed to be revolutionary, but her work was the foundation of a new approach to mathematics.

While Noether published ground-breaking papers at Erlangen, she had no title or salary; she was only able to occasionally cover for her father's maths lessons when he was sick.

After seven years of this, the mathematicians David Hilbert and Felix Klein invited her to work with them at Gottingen University. They wanted her to solve the confounding problem of energy conservation in Einstein's theory of general relativity. In the course of figuring this out, Noether produced one of the most important insights in theoretical physics, which came to be known as Noether's theorem.

Einstein described the theorem as a piece of "penetrating mathematical thinking". Yet it can be stated quite simply: whenever there is a symmetry of nature, some fundamental quantity is conserved. Symmetry refers to when a physical process – or a mathematical description of one – stays the same when you change some aspect of the set-up.

For example, a perfect pendulum, swinging back and forth forever, is symmetric in time. Noether's theorem, tells us that anything with time-translation symmetry conserves energy. So the pendulum loses no energy. Likewise, if a system has rotational symmetry, it works the same facing any direction and conserves angular momentum. This means that once an object is spinning, it will keep spinning. The stability we see in the orbits of the planets is a consequence of these symmetries working together: the conservation of both the energy and angular momentum of the bodies.

Noether's theorem allows us to make deep connections between the results of experiments and the fundamental mathematical description of the physics governing them. Thinking about physics in this way formed the basis of the kind of theoretical leap that led physicists to theorise the Higgs boson long before it showed up in the Large Hadron Collider. Symmetry is so fundamental to physics that the standard model of particle physics is frequently referred to by its symmetry groups: $U(1)\times SU(2)\times SU(3)$.

Revolutionising theoretical physics was well and good, but Noether was still working without pay, often teaching under Hilbert's name, officially his "assistant". In 1922, four years after publishing her theorem, she was named "associate professor without tenure" with a small salary. She lectured all around Europe.

Then the Nazis came. Noether was Jewish, and when the Nazis took power she was out of a job. Noether fled to America and became a visiting professor at Bryn Mawr College, also giving weekly lectures at Princeton. At Bryn Mawr, for the first time, she had female colleagues in mathematics. Tragically, she had only two years to enjoy this. Noether died in 1935 after complications from surgery when she was 53. Many of the great physicists and mathematicians of the day eulogised her, including Einstein.

In Noether's time, the scientific establishment worked hard to keep women out. A genius of Noether's calibre, with Einstein's backing, could *maybe* be included. Even today, in mathematics or physics, we can observe an asymmetry in the treatment of women and men in academia.

And as Emmy Noether taught us, whenever a symmetry is broken, that means something is being lost.

LAURIE ZOLOTH is a professor of medical ethics & humanities at Northwestern University, Chicago.

PHILOSOPHER'S CORNER

Designer babies crawl closer

Are humans mature enough to engineer human embryos?

SUPER CROPS and healthy productive farm animals; mosquito populations controlled without pesticides; a cure for cancer ... This fantasy world has loomed since the 1970s when we first learnt how to edit DNA, the code of life.

But the technology to do so turned out to be cumbersome, costly and unreliable. The failure rate in animal tests was so high that fixing a person's genetic disease became out of the question.

This began to change with the discovery of proteins purpose-built to modify DNA: so-called zinc finger nuclei in the 1990s and TALENS in 2009. The success rate climbed high enough to start clinical trials: zinc finger nuclei were used to make human immune cells resistant to HIV, and TALENS was used to repair the gene that causes Severe Combined Immunodeficiency (SCID).

And then scientists uncovered a new DNA-editing strategy in bacteria, used to edit out invading viruses. It was a modular system composed of proteins and RNA, termed CRISPR. And like all modular systems, it offered amazing versatility. The protein module (CAS 9) was a missile that destroyed DNA. The variable RNA module provided exquisite guidance.

Suddenly, the prospect of gene therapy moved to the fast track.

Too fast! The precision, ease and affordablity (a CRISPR-CAS 9 kit costs $100), worried University of Berkeley scientist Jennifer Doudna, co-discover of the technique. She led a group of 18 – including scientists who use CRISPR and two ethicists – to pen a letter to *Science* magazine in March. They recommended steps be taken to "strongly discourage ... attempts at germline [embryo] genome modification for clinical application in humans, while societal, environmental, and ethical implications of such activity are discussed among scientific and governmental organisations".

Biotechnology researchers imposed a moratorium on genetic engineering at the 1975 Asilomar Conference on Recombinant DNA. The US Recombinant DNA Advisory Committee, which reviews every proposed clinical trial of gene therapy (and of which I am a member) was also established at this time.

"Germline" genetic modification is code for engineering embryos. It has been rejected by every political, religious and ethical body that has considered it. In Australia and much of Western Europe, it is legally banned. The US does not have a legal ban. US companies such as OvaScience in Massachusetts, experiment on human egg cells and embryos with a view to eliminating disease genes.

This was once the stuff of science fiction. No longer. The week after Doudna's letter to *Science*, Chinese scientists reported they had attempted to correct beta thalassemia, a blood disease, by using CRISPR to edit the defective gene in human embryos. They deflected some criticism by using embryos rejected by an IVF lab (because they had been fertilised by two sperm) that would never be implanted in a womb.

But CRISPR did not live up to its reputation. It worked on only a fraction of the 86 "edited" embryos. In other cases random sections of DNA were altered which would have disastrous consequences for the embryo. Despite this failure the Chinese and the US are continuing to refine the technique.

What would it mean to eliminate the Tay-Sachs mutation, a fatal childhood disease, forever? Or to make babies without cystic fibrosis? George Church at Harvard cites a list of 10 naturally occurring beneficial genetic variations we might give to babies. They include extremely hard bones, resistance to cancer, HIV and Alzheimer's and insensitivity to pain. Philosophers, theologians and lawyers have had three decades to ponder such claims. Many of our fears have proved wrong: genetically altered *E. coli* have not escaped, and all those containment labs for early genetic research now seem silly. This time, the genetic modification of embryos may be real, and in time, safe and available to prospective parents. Now is the time to think about the questions this raises.

I suspect we would reach the same conclusions we did 30 years ago: our knowledge of unforeseen consequences is too poor; our capacity for greed and narcissism too strong; our society already too unjust to begin to design babies to a spec sheet.

ALAN FINKEL is an electrical engineer, neuroscientist and the publisher of *Cosmos* magazine.

INCURABLE ENGINEER

A comfortable home, alone in the Universe

The search for intelligent life elsewhere in the cosmos is a waste of time.

SOME PEOPLE HATE TO BE ALONE. They like to think there must be somebody or something out there, beyond the limits of the Solar System. I see it otherwise – the possibility that we are the first intelligent species makes me feel special.

I've been contemplating the status of humankind because of two recent announcements. First, the Kepler Space Telescope team announced that they found an Earth-like planet named Kepler-452b in our galaxy, a mere 1,400 light-years from Earth.

Second, the search for extra-terrestrial intelligence, SETI (now in its 55th year of listening to resounding silence), received a boost with the announcement that Yuri Milner, a wealthy Russian technology investor, will donate $100 million to give the program a makeover.

As a species we are naturally curious about whether we are alone. Milner believes the reason we've not found extra-terrestrial life is because haven't searched hard enough. As he put it: if you put a cup in the ocean and draw it out empty, that doesn't mean there are no fish.

But it could mean no fish.

The holy grail is for us to find a technologically advanced civilisation, not just the chemical building blocks of life such as we hope to find with the Mars rover missions. What kind of signal are we looking for?

Let's say there is an intelligent civilisation on Kepler-452b and that they have built a powerful transmitter to send signals to us. If we picked up such a signal today and responded, our signal would take 1,400 years to reach them. Their response would take just as long, so it would be our descendants 2,800 years from now who would receive the reply. That would make for a rather drawn out conversation.

Even if they did not think of sending us a signal, by pointing our radio telescopes at Kepler-452b we might find echoes of their radio, television or equivalent broadcast transmissions.

The trouble is that all broadcasts are subject to the inverse square law: every time you double the distance from the source, the signal strength falls to a quarter.

As a consequence, any signals not specifically directed at us, travelling thousands of light-years, would be so weak by the time they reached Earth they would be lost in the background noise of the Universe. No amount of computer processing could extract those signals from the noise.

Given that the chance of detecting a signal, let alone any hope of a conversation, is highly remote, let's revert to logic to consider what other life-forms might be like. Assume that there is indeed one other planet teeming with life. Either it is more technologically advanced than us or less so.

Given that the Universe is 13.7 billion years old this other life-form is unlikely to be a mere few hundred years ahead or behind. There is a good chance that there will be a substantial difference, with its development something like 500 million years ahead of us or 500 million years behind. If it is that far behind us – think trilobites – it will not be sending out radio signals.

If it is that far in front of us, what would that mean?

Start by imagining our own technology 500 years hence. That is completely beyond my ability to conceive.

Now what if the alien life were 500 *million* years ahead of us? They would be god-like, with technology absolutely beyond our comprehension. They would be curious, so by now they would have found us. They would certainly be capable of choosing whether or not to make contact.

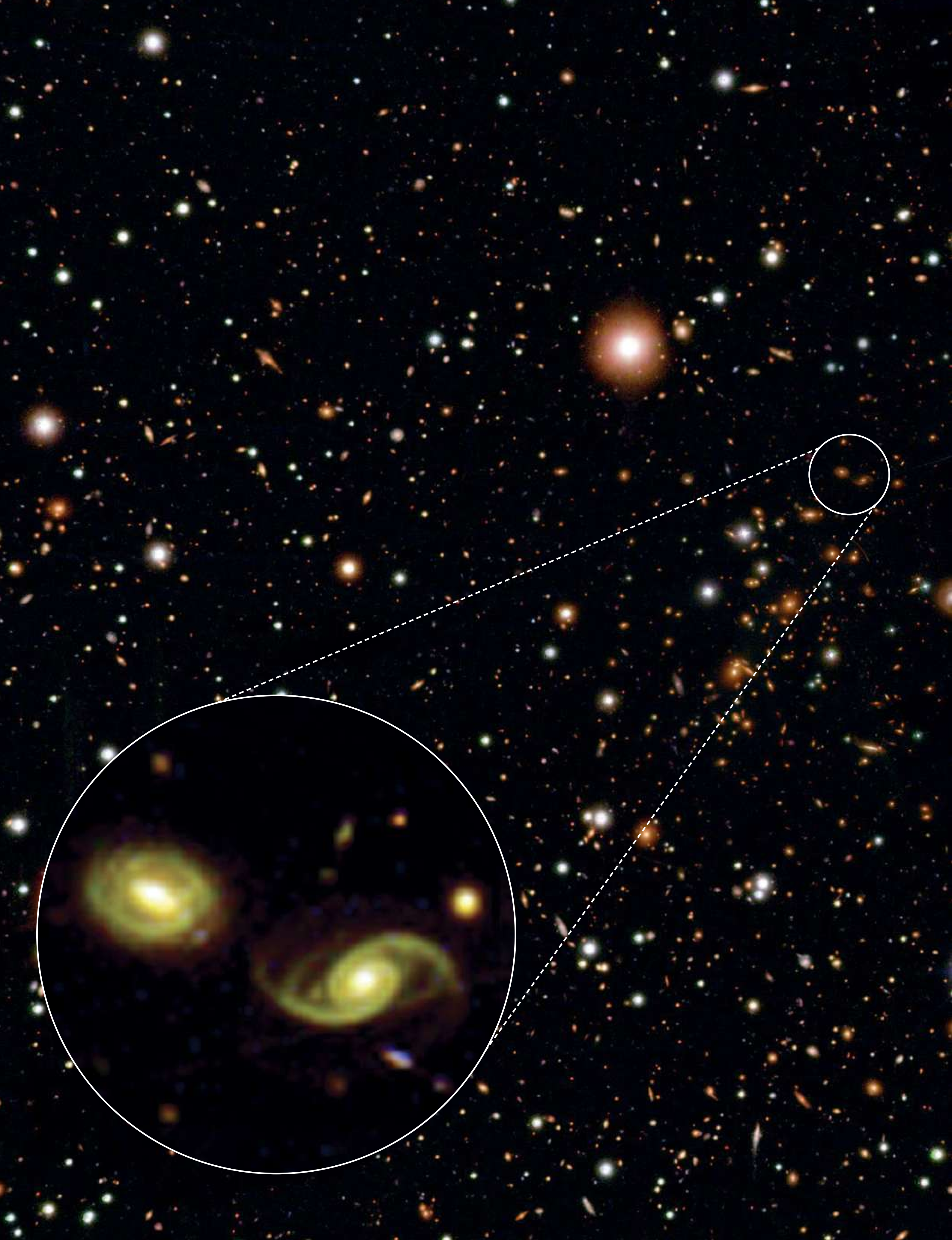
> THE POSSIBILITY THAT WE ARE THE FIRST INTELLIGENT SPECIES MAKES ME FEEL SPECIAL. IN EVERY RACE, SOMEBODY HAS TO BE FIRST.

However, there is no evidence of their existence. Perhaps they have turned their noses up at us and moved on?

Maybe.

But my hunch is that we are the most advanced species in the Universe, certainly in our galaxy.

In every race, somebody has to be first. In this evolutionary race, it's us.

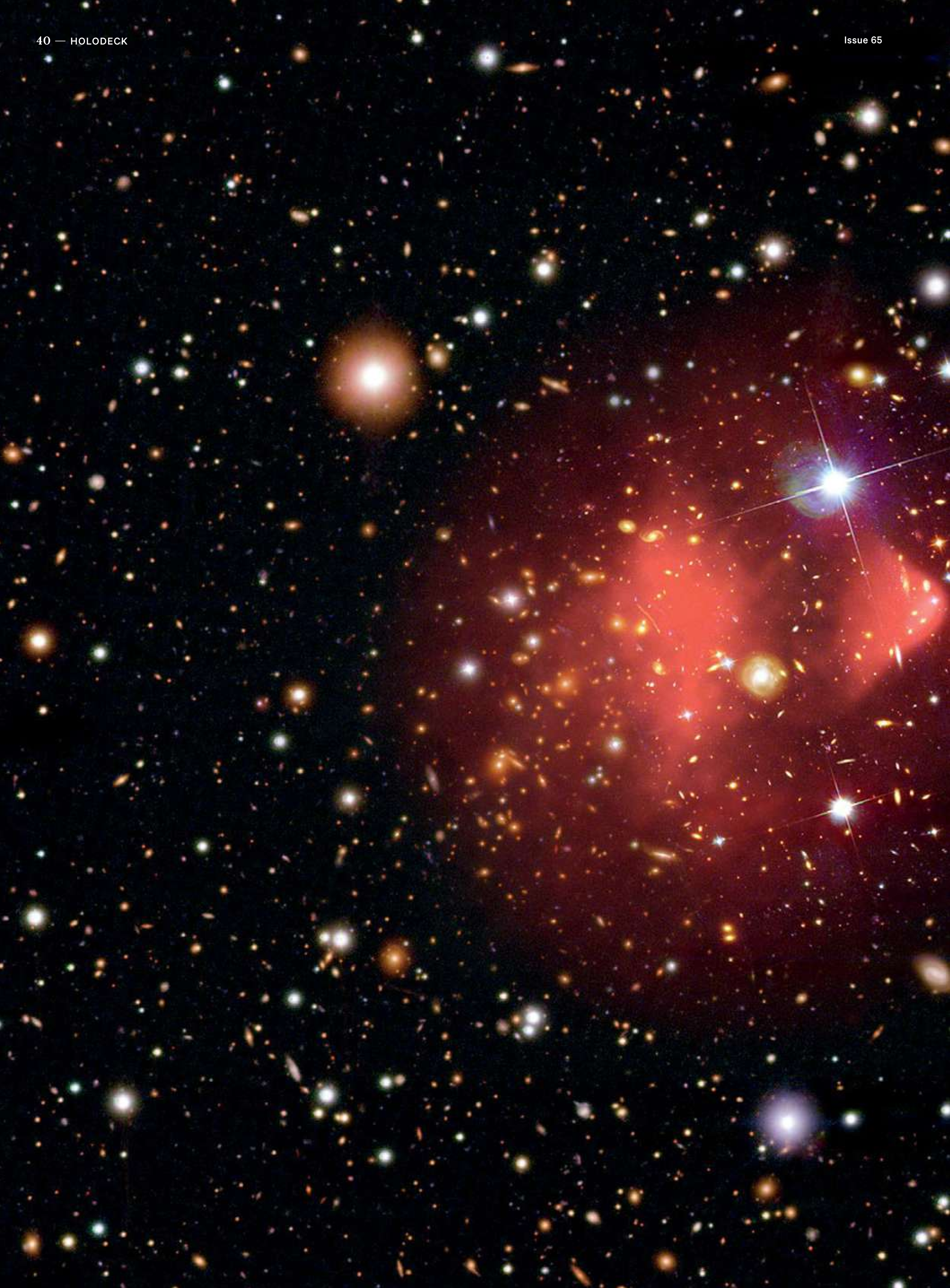


HOLODECK:
COMPILED BY JAMES MITCHELL CROW

DARK MATTER REVEALED

MOST OF THE MATTER in the Universe consists of stuff we can't see. It is dubbed "dark matter" and we know it must be out there. Without dark matter rapidly spinning galaxies (such as those circled, left) would not have sufficient gravitational glue to hold their stars and gas clouds together. These elements would fly off into space instead, like rain drops on a spinning bicycle wheel. What might this ghostly, galaxy glue be made of? Nobody knows. But in 2006 astronomers got a new clue.

CREDIT: NASA / STSCI; MAGELLAN / U. ARIZONA / D. CLOWE ET AL.



X-RAYS OF A BULLET CLUSTER

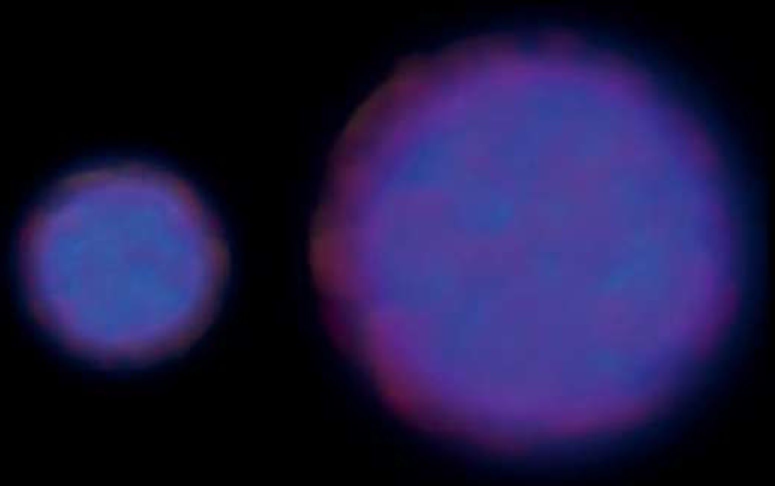
In 2006, NASA astronomers aimed their orbiting Chandra X-ray Observatory at the galaxy cluster shown on the previous image, 1E 0657-56. It captured a very different picture.

Chandra picks up the X-rays given off by hot clouds of gas (shown here in red, overlaid on a Hubble snapshot). The striking shape of the newly revealed gas clouds earned them an instant nickname: the bullet cluster.

But the bullet cluster had a bigger secret to reveal.

CREDIT: NASA, ESA, J. JEE (UNIVERSITY OF CALIFORNIA, DAVIS), J. HUGHES (RUTGERS UNIV.), F. MENANTEAU (RUTGERS UNIVERSITY & UNIVERSITY OF ILLINOIS, URBANA-CHAMPAIGN), C. SIFON (LEIDEN OBS.), R. MANDELBUM (CARNEGIE MELLON UNIVERSITY), L. BARRIENTOS (UNIVERSITY CATOLICA DE CHILE), AND K. NG (UNIVERSITY OF CALIFORNIA, DAVIS)

1



2

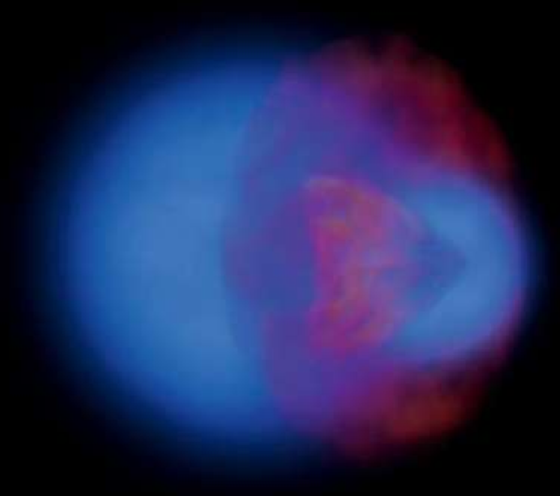
WHEN GALAXIES COLLIDE

Astronomers think the bullet cluster began to form around 100 million years ago, when one small cluster of galaxies barrelled right through the middle of a larger cluster, and out the other side. This four-step artist's illustration depicts the sequence of events.

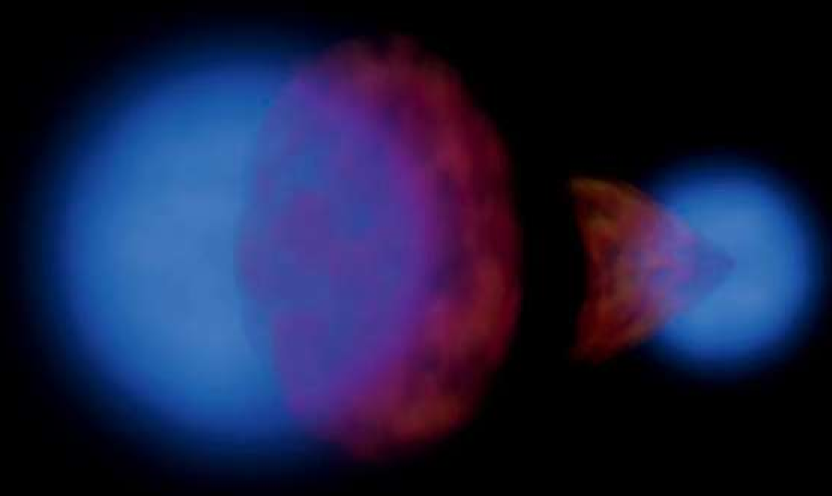
The colliding gas particles in each galaxy are shown in red. As the little gas cloud elbowed its way past its bigger partner it acquired its dramatic bullet shape.

CREDIT: NASA / CXC / M. WEISS

3



4



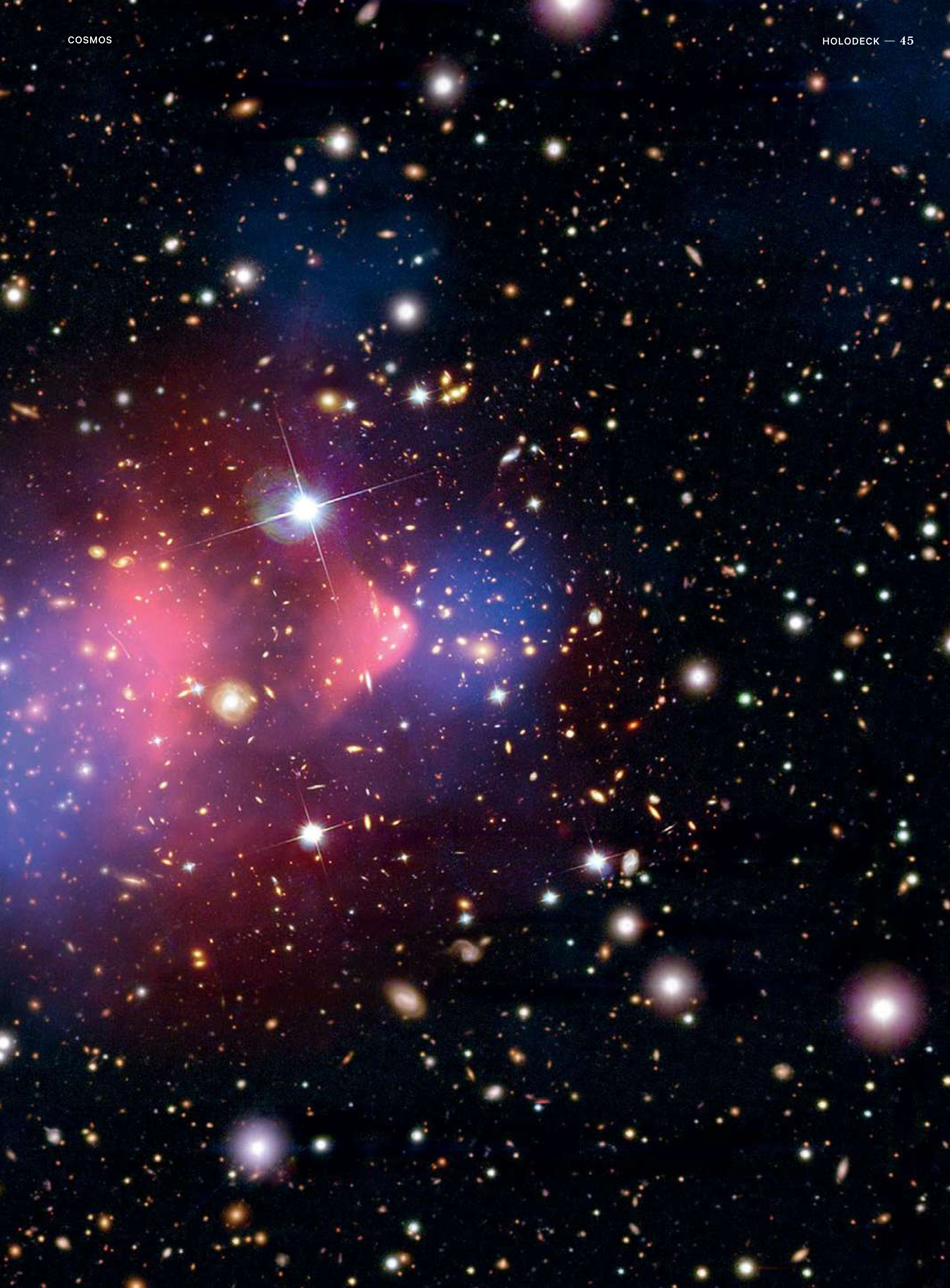
DARK MATTER REVEALED

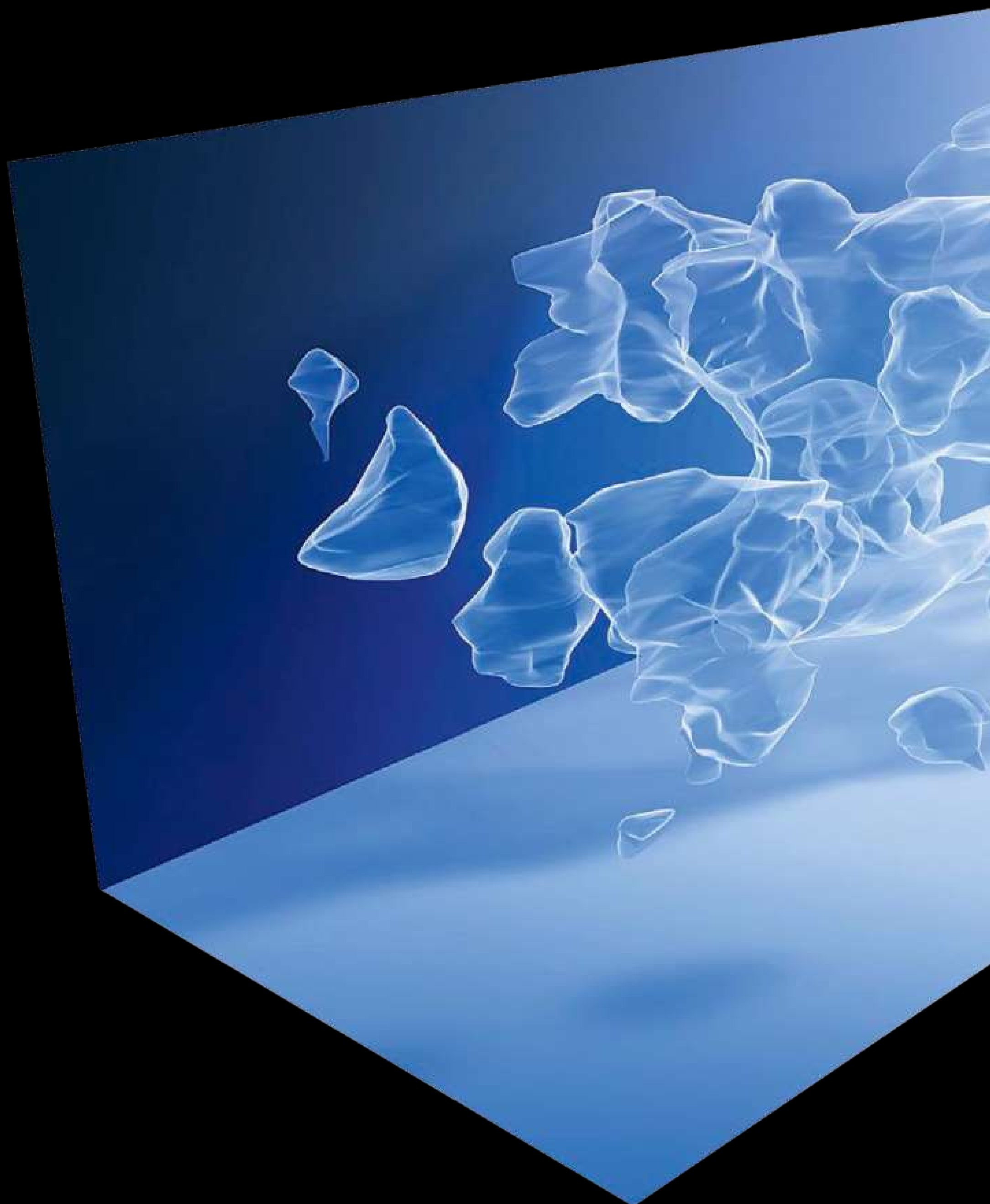
What about the dark matter?

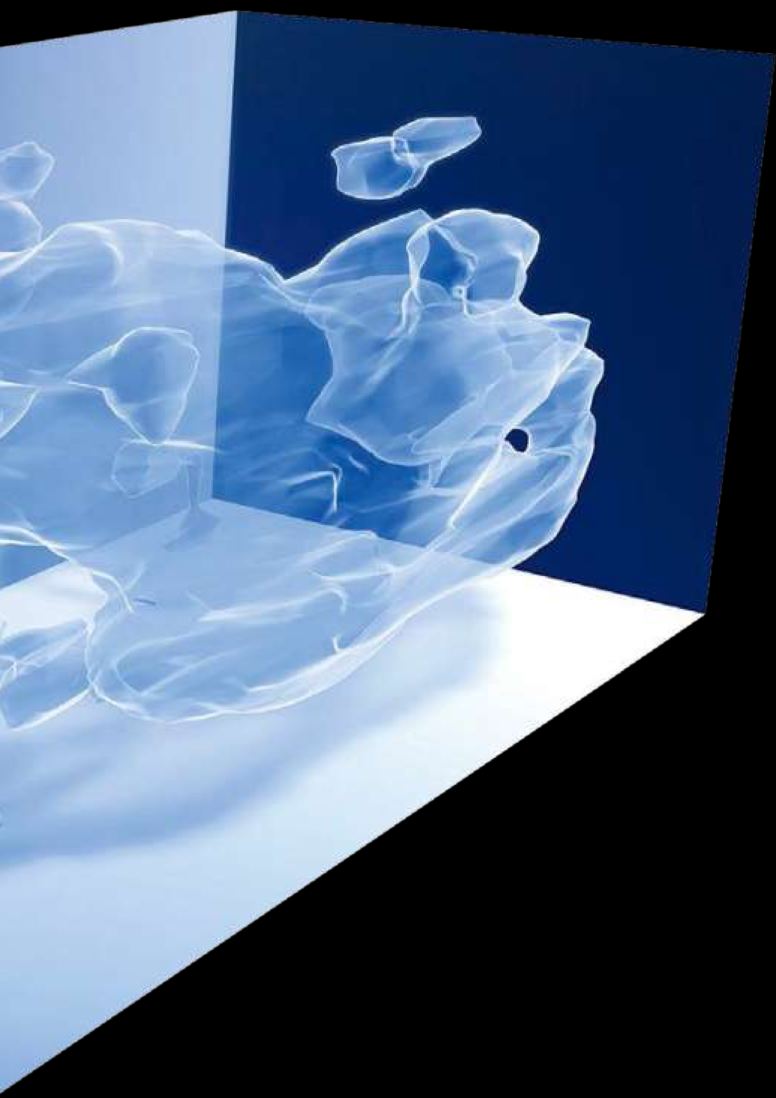
Astronomers can track the location of dark matter because its gravity bends the light of stars behind it. The technique is called “gravitational lensing”. Using the Hubble Space Telescope, they were able to see where the dark matter was located in the bullet cluster (violet shading).

While the gas particles jostled and elbowed their way past each other, the dark matter particles slipped right past unnoticed – just what you’d expect from ghosts.

CREDIT: NASA / CXC / CFA /M. MARKEVITCH ET AL.; OPTICAL: NASA / STSCI; MAGELLAN / U. ARIZONA / D. CLOWE ET AL.; LENSING MAP: NASA / STSCI; ESO WFI; MAGELLAN / U. ARIZONA / D. CLOWE ET AL.







GHOST MAP

It may be ghostly but the Hubble telescope can detect dark matter because of the way it bends light from stars. Using this information, in 2007 astronomers mapped its location in the Universe and how it has changed over billions of years (pictured).

In the early days of the Universe (far right), dark matter was spread out quite evenly. But over time, gravity collapsed this structure into dense clumps (far left).

Some astronomers think these dark matter clumps created an essential scaffold. Ordinary matter was drawn to it and started forming stars, galaxies and ultimately, ourselves.

CREDIT: NASA / ESA / R. MASSEY (CALIFORNIA INSTITUTE OF TECHNOLOGY)

“The kids really get into the lessons. They work the whole time and you could hear a pin drop.”

– Damian, science teacher

GENERAL RELATIVITY, STILL AHEAD OF ITS TIME

A century ago Einstein sweated blood to give us his mind-bending theory of gravity. As technology caught up, his predictions were verified, one by one. Now only gravitational waves remain. By DAN FALK.

"I CANNOT FIND TIME TO WRITE *because I am occupied with truly great things. Day and night I rack my brain in an effort to penetrate more deeply into ... the fundamental problems of physics."*
— Albert Einstein, in a letter to his cousin Elsa, 1914.

"I WOULD HAVE TO FEEL SORRY FOR GOD, BECAUSE THE THEORY IS CORRECT."

BEETHOVEN SPENT MORE THAN 16 hours a day at his piano, sometimes composing four musical works at once. Immersed in his task, he would become feverish, often dousing himself with water that soaked through the floor into the apartment below.

If we could time-travel to Berlin between 1905 and 1915, we would likely find Albert Einstein at the height of his powers, in a similarly febrile state. Yet he pushed on with his equations knowing, as he hinted in the letter to his cousin, that "great things" were within his reach.

Einstein had already achieved greatness. In 1905 he developed the theory of special relativity that wove space and time together into the fabric of the Universe and gave us $E=mc^2$.

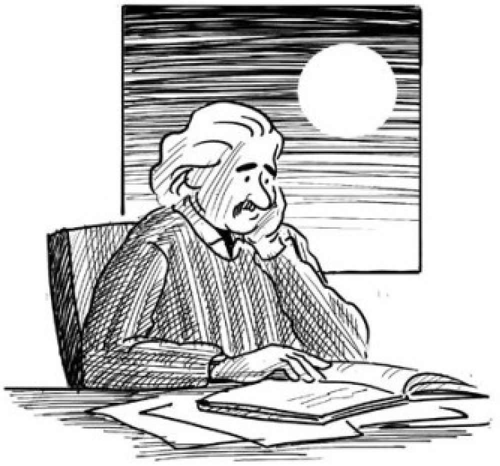
But Einstein was just getting started. He realised gravity needed to be brought into the picture. For several years, he could not see how to do it. "In all my life I have laboured not nearly as hard; compared with this problem, the original relativity is child's play," he told a colleague. His eureka moment was to realise gravity worked by warping the fabric of space-time. Towards the end of 1915, Einstein produced his masterpiece: the general theory of relativity.

This year, physicists are celebrating the centennial of Einstein's theory. They are looking back on the theory's origins, its growing pains, how it is holding up. And they are devising experiments to test the theory under ever more exotic conditions, to see if, or where, it may falter. And most of all they are looking ahead, pondering the *next* theory – one that can reach even further than Einstein's, by incorporating the other great idea of 20th century physics: quantum mechanics.

But for now, Einstein's theory reigns supreme. "There's not a single experiment that has gone against it – at least, not one that's ever been confirmed," says Clifford Will, a physicist and general relativity expert at the University of Florida in Gainesville. "It's passed every test with flying colours."

THE NOTION OF RELATIVITY was not invented by Einstein. Scientists as far back as Galileo had pondered the consequences of relative motion. Indeed most of us have experienced relativity – perhaps an unnerving moment on a train when you notice a train on a parallel track and wonder which of you is moving. Suppose you and a friend are riding a train moving at 200 kilometres per hour. You throw a baseball to your friend, who's further forward in the train, at 100 km/h. How fast is the ball moving relative to the ground? You simply add the two speeds together and get 300 km/h. If your friend throws the ball back, its speed relative to the ground is now 100 km/h.

This is the answer Newton would have given. Like most of us, he imagined space and time were absolute and unchanging – the fixed backdrop against which the events of the Universe unfolded.



However, this common-sense view of the Universe struck a problem concerning light. In 1865 James Clerk Maxwell showed light was really an oscillating electromagnetic wave; moreover he calculated that it travelled at a constant speed of about 300,000 kilometres per second.

01

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

Einstein's maths is hard to follow; metaphors help.

A constant speed – but relative to what?

If instead of a baseball, you flashed a torch at your friend on the train, would the speed of the light beam be added to the speed of the train? And would you subtract the speed of the train if you flashed it in the opposite direction?

One idea – popular in the late 19th century – was that light waves propagated through an invisible "ether", just as ocean waves propagate through water. If that were the case, the speed of light would vary relative to the Earth's movement through the ether. In 1887 American scientists Albert Michelson and Edward Morley performed an experiment to see if this was the case. (Essentially, they shone a beam of light in different directions to see if light moving "with the ether" moved faster than light moving "against the ether". They also tried the experiment at different times of the day and year, to see if the Earth's rotation and its orbital motion had any effect.) Their result: the speed of light was always 300,000 km/s.

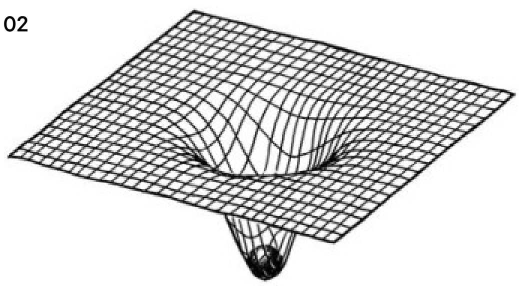
Simply put, you can't boost or slow a beam of light as you can a baseball: shine a flashlight from a train and its speed – relative to you, relative to the ground, relative to anyone anywhere – will be 300,000 km/s. Similarly, no matter how much you increase your own speed, you can't catch up to a beam of light.

This vexed the young Einstein. Whether he knew about the Michelson-Morley result, and how much it influenced him, is unclear – but his "thought experiment" about riding a bicycle alongside a beam of light was already leading him away from classical physics. (If you *could* catch up to the beam of light, it would appear motionless – but what does a motionless wave even mean?)

His answer was special relativity. Speed is distance divided by time. So if the speed of light isn't affected by the motion of the observer, then *space and time must be*. As your speed increases, time expands or "dilates" and distance is shortened in the direction of motion. So moving clocks run more slowly (this is why satellites need to adjust their time). And remember the case of the baseball thrown on the train? Einstein showed that, relative to the ground, the ball *isn't* travelling at 300 km/h, but fractionally less.

SPECIAL RELATIVITY WOVE space and time together into the fabric of the Universe. It was astounding – yet something was missing. Gravity. In 1907 Einstein had an epiphany that put gravity in the picture. Gravity, he said, warped the fabric of space-time.

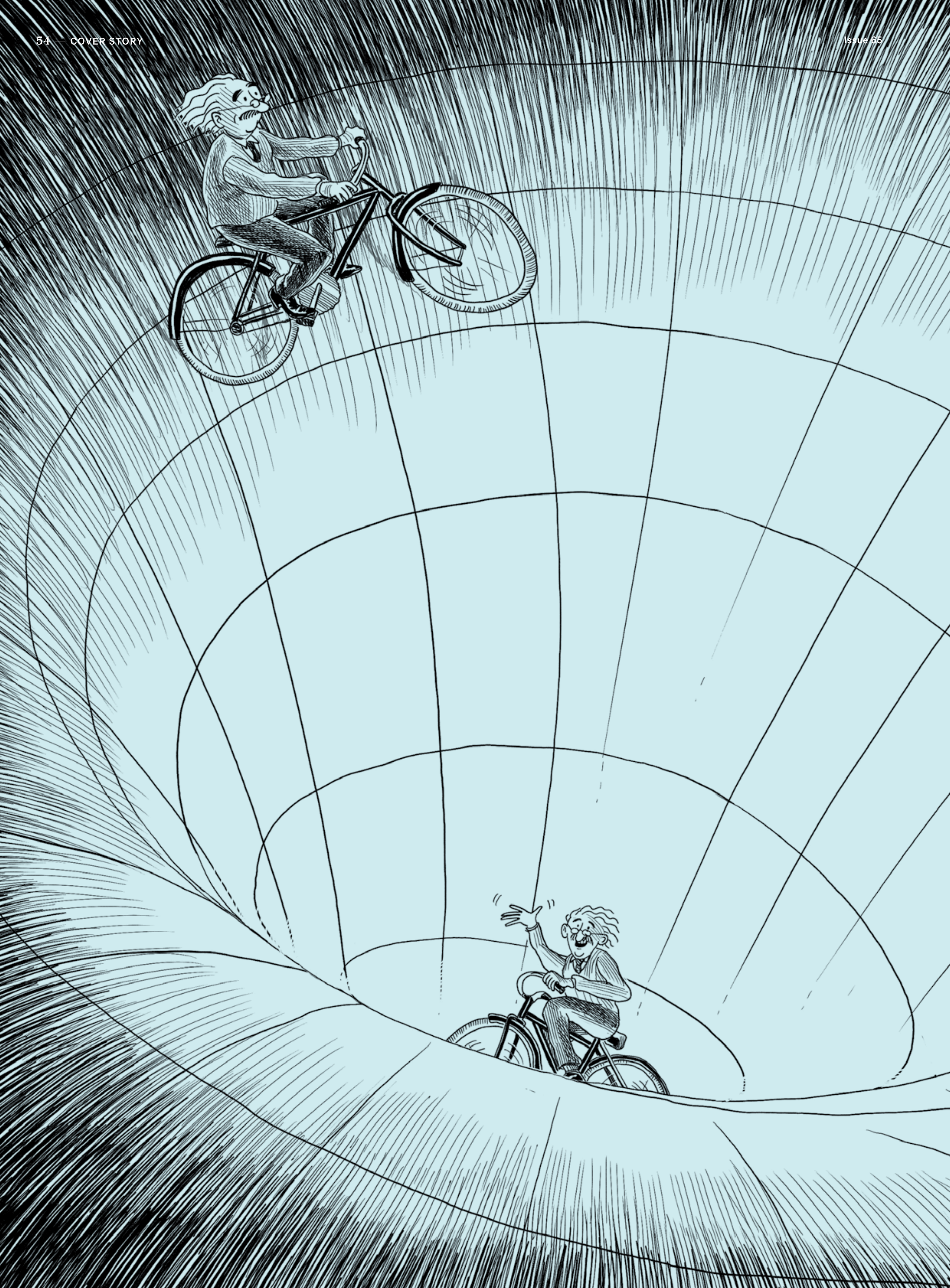
02

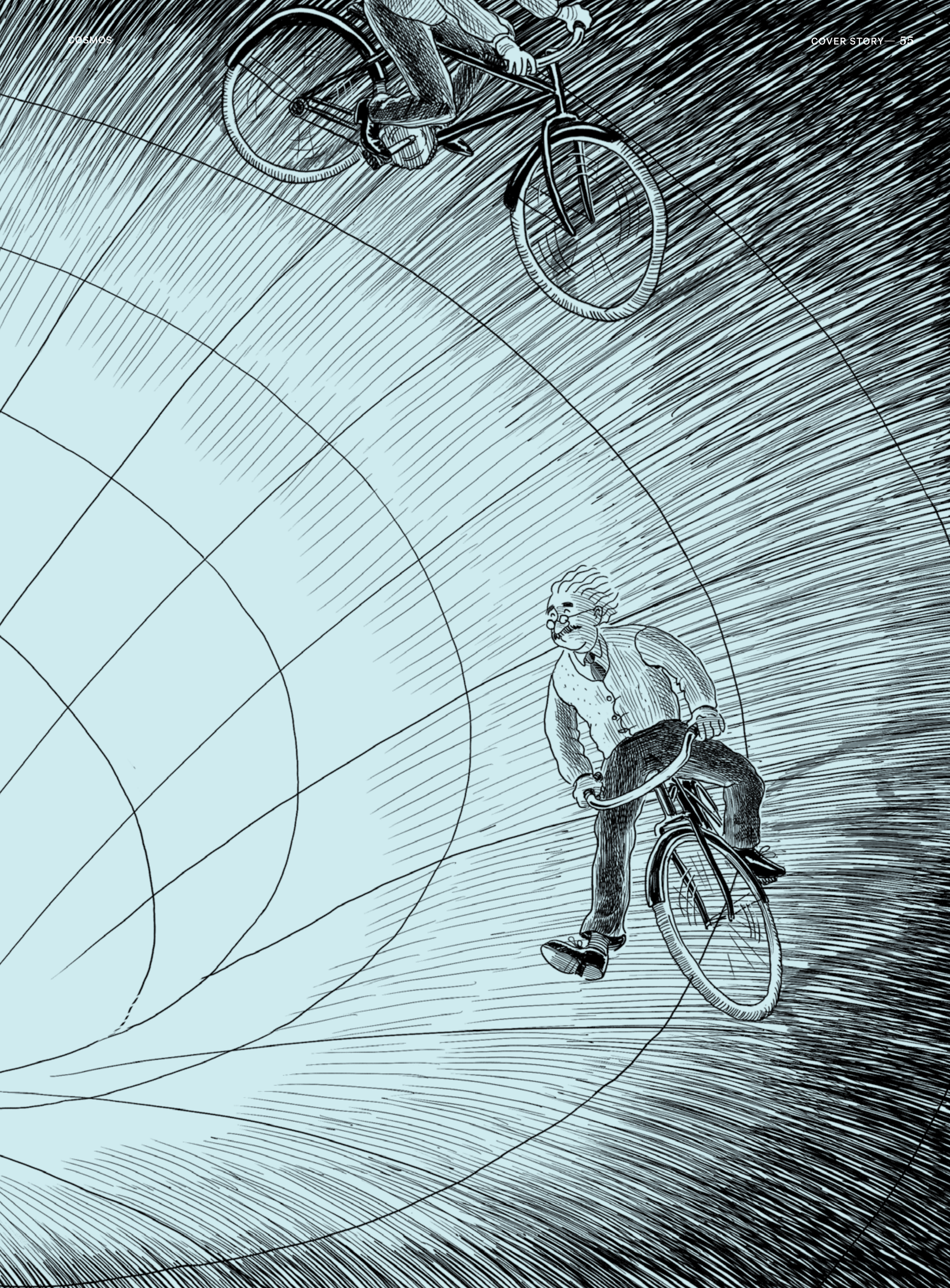


Just as a bowling ball distorts a rubber sheet, so gravity warps the fabric of the Universe.

Einstein realised the effect of gravity is *just like* the effect of acceleration. When you accelerate, you feel a force that is indistinguishable from gravity – think of being pressed to the floor in a rising elevator. Moreover objects with different mass respond to gravitational acceleration in the same way. As Galileo showed, heavy and light objects fall at the same rate. The only possible explanation, Einstein realised, is that gravity isn't a property of matter, but of space-time. For the next eight years Einstein laboured to express the details of the theory in mathematical terms. In November 1915, he captured them in four publications that defined his general theory of relativity.

The mathematical details are complex but, thankfully, we have a useful metaphor. No doubt Einstein would have approved – he made great use of metaphors. Imagine a bowling ball on a rubber sheet. The sagging is most pronounced in the area closest to bowling ball – this is the "warping" of space. Now imagine rolling a marble across the same sheet. As it passes near the bowling ball, its path will curve because of the warping of the sheet – this is reminiscent of how our Earth curves around the Sun. (Gravity actually warps time as well as space – they are connected.)





This seemingly fantastic theory of how gravity curves space-time was first put to the test to explain the strange orbit of Mercury. Since the mid-1800s, astronomers had noticed that instead of tracing an ellipse around the Sun, as predicted by Newton's laws, Mercury's orbit shifted slightly with each rotation. General relativity provided the answer: as the closest planet to the Sun, Mercury experienced the greatest warping of space-time, explaining the slight but detectable deviation in its elliptical orbit.

General relativity also predicted that light would be affected by the warping of space-time. British astronomer Sir Arthur Eddington tested that prediction by observing the Hyades star cluster when the Sun's path took it directly in front of the cluster. Normally, the Sun is too bright to allow such a measurement – but on May 29, 1919, a solar eclipse made it possible. Eddington led an expedition to the island of Principe off the west coast of Africa and sent another team to Brazil (in case Principe had cloudy weather). The relative position of the stars in the cluster was compared to the way they looked several months before, when the cluster was well away from the Sun.

Einstein was proved right; the light from the stars in the cluster *was* bent as it passed the Sun, shifting their relative positions by the amount predicted by the theory. The British astronomers presented their results at a meeting in London in early November. Back in Berlin, Einstein was perfectly calm. When someone asked him what he would have done had the eclipse measurements not confirmed his theory, he replied: "In that case, I would have to feel sorry for God, because the theory is correct."

THE LONDON ANNOUNCEMENT, picked up by newspapers in Britain and America, made Einstein a superstar; he would remain a media darling for the rest of his life. Yet at the same time physicists were loathe to ditch Newton for Einstein.

"There was a lot of doubt about the theory, in many quarters, for quite a long time," says Clifford Will. "The lack of strong experimental evidence, coupled with the fact that no one could see how it would ever be important in astronomy, plus a lack of understanding of what the theory really meant ... all of that caused the entire subject to go into decline for almost 50 years."

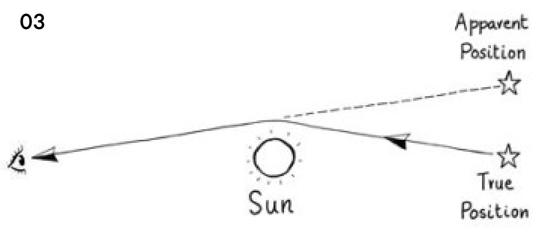
The next crucial experiment was not carried out until 1959. General relativity predicted that light and other forms of radiation ought to be stretched in a gravitational field, an effect known as "gravitational redshift". To put this idea to the test, physicists at Harvard placed a sample of radioactive iron in a basement where the gravitational field is stronger because it is closer to the centre of the Earth. They carefully measured the wavelength of the radiation that reached a detector on the roof (a distance of 22.5 metres), then switched the experiment around, putting the radioactive sample on the roof and the detector in the basement. Sure enough, when the radiation came from the basement the wavelength was ever so slightly longer compared to when it came from the roof. Gravity had indeed stretched the radiation waves.

General relativity also predicted that gravity stretches time. So a clock at the base of a mountain should run slower than a clock at the peak because the lower clock feels the Earth's gravity more intensely. Detecting that tiny difference had to await the 1970s, when fleeting time intervals could be routinely measured by atomic clocks. By 2010, physicists were able to measure the discrepancy between two atomic clocks placed one-third of a metre above one another. Each second, the lower clock, being closer to the Earth, lost four-hundred-quintillionths of a second relative to the higher clock.

That may sound trivial, but it has a practical application. For our Global Positioning System (GPS) devices to work, they have to track signals received from an array of satellites to within billionths of a second. The effect from gravity is about 38 microseconds per day. Left uncorrected,

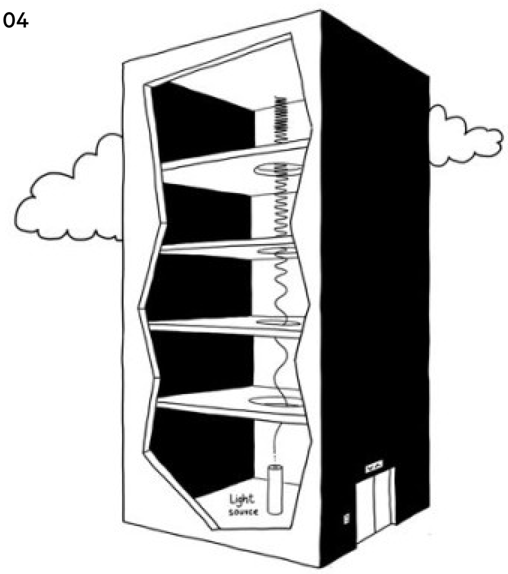
the discrepancy would cause our navigation systems to accumulate an error of some 10 kilometres over the course of a day. So the next time you find a bus stop in an unfamiliar city with GPS, thank Uncle Albert.

03



Light from distant star will bend as it passes our Sun, due to the Sun's gravitational field. The effect was first measured during a 1919 eclipse.

04

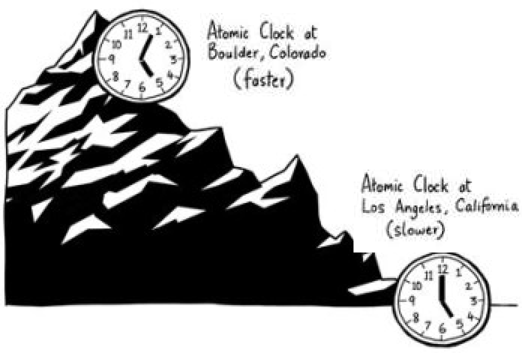


Earth's gravitational field stretches space-time. Radiation emitted at the bottom of a tower has a longer wavelength than it does at the top.

PERHAPS GENERAL RELATIVITY'S most remarkable prediction was the existence of exotic objects that warp space and time so severely that they become cut off from the rest of the Universe. If you saw the movie *Interstellar*, then you got to see one up close (or at least how we imagine they'd look). We're talking, of course, about black holes. According to general relativity, a black hole can form when a massive star collapses after exhausting its nuclear fuel supply. If the star is big enough, the collapsed core will have such an intense gravitational field that nothing, not even light, can escape. Anything that crosses the "event horizon" – the boundary of the black hole – is trapped forever.

By definition, black holes cannot be seen directly. We infer their presence from their effect on surrounding matter – either from their effect on the motion of a companion star, or by detecting X-rays given off by matter as it is sucked into the black hole. There's also mounting evidence that "supermassive" black holes lurk in the centres of most galaxies, including our own Milky Way. Within the next decade, we may get to find out if *Interstellar's* simulation got it right. The Event Horizon Telescope, an array of radio telescopes spread across the globe, will examine the region immediately surrounding the event horizon of the Milky Way's central black hole.

05



Because the Earth's gravity is stronger at the foot of a mountain than at its peak, a clock will tick more slowly down below than up on top.

Black holes stretch space-time; they also stretch Einstein's theory to its limits. One problem is the so-called singularity said to lie in the centre of a black hole. At a singularity, space and time are infinitely stretched. That's both mathematically and physically awkward, to say the least. What can "infinite stretching" mean? And it gets worse. In the 1970s, Stephen Hawking applied quantum mechanics to the mathematical description of a black hole, and what he discovered was startling: black holes aren't so black. Instead, they emit so-called Hawking radiation; given enough time, a black hole should completely evaporate away.

"We still don't have a terribly good grasp of what's going on there," says William Unruh, a physicist at the University of British Columbia in Canada. But probing black holes might get us closer to completing Einstein's unfulfilled quest to unify the physics of the very small and the very large.

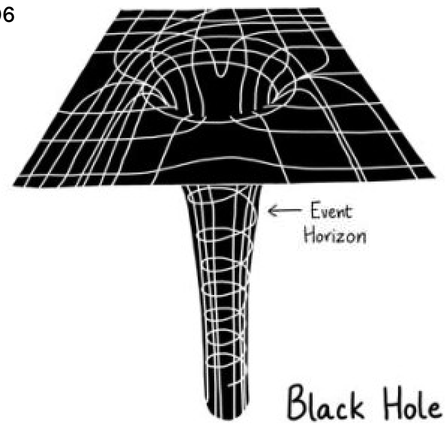
"We might get a little more insight into how quantum mechanics and gravity could be married to each other," says Unruh.

PROBING BLACK HOLES MIGHT GET US CLOSER TO COMPLETING EINSTEIN'S QUEST TO UNIFY THE PHYSICS OF THE VERY SMALL AND VERY LARGE.

IT'S TAKEN A CENTURY, so far, to develop the technology to test Einstein's predictions. It may take a little longer for the last piece of the relativity puzzle: the existence of gravitational waves. These ripples in space-time should be emitted when massive objects are accelerated. Just as a bowling ball dropped on to a rubber sheet would cause it to ripple – alternately stretching and shrinking the fabric – so too, the waves from massive, accelerating objects should ripple space-time as they pass by. But Einstein predicted the ripples would be so weak it would take cataclysmic events to produce the feeblest wave. He never expected it would be possible to detect them.

"GENERAL RELATIVITY IS SO … BEAUTIFUL AND SIMPLE."

06

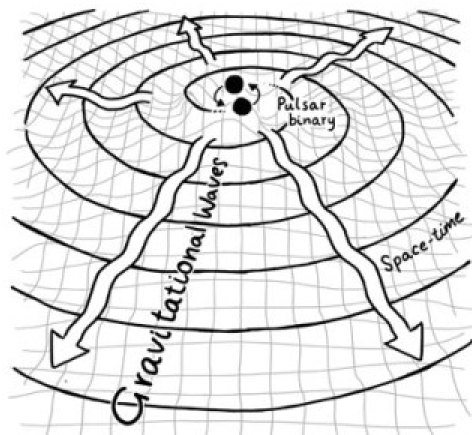


Einstein foresaw that a black hole can warp space-time so severely that it becomes "cut off" from the rest of the Universe.

Indeed we haven't yet detected them directly but there *is* indirect evidence that gravitational waves exist. One piece comes from rotating neutron stars known as pulsars. Barring black holes, neutron stars are the densest objects in the Universe – formed after a massive star explodes into a supernova and its protons and electrons collapse into a core of neutrons. They are so dense that a teaspoon of neutron star material would weigh around a billion tonnes; gravity on their surface is 10^{11} times that on Earth. Rapidly spinning pulsars emit a narrow beam of radio waves; if the beam happens to be lined up with Earth, we see a periodic flash, as if from some cosmic lighthouse. Pulsars occasionally team up with an ordinary star to form a binary system. As the massive pulsar spins around its companion, stirring up space-time, it should emit gravitational waves.

Since the 1970s, astronomers have been observing a pulsar (with the unpoetic name of PSR B1913+16), that is partnered with an ordinary star. According to general relativity, the gravitational waves emitted by the system should cause their orbit around each other to shrink, something that can be measured by tracking the timing of the radio pulses – and this is exactly what astronomers have seen. This tightening of their embrace could not be explained by the energy radiated away by radio waves alone.

07



Massive accelerating bodies stir up space-time and radiate gravitational waves.

The more cataclysmic the event, the better our chances of detecting gravitational waves. So it is no surprise physicists have been trying to detect the ripples created by the Big Bang itself. Last March, a team of astronomers training their radio telescope at the radio-friendly skies of the South Pole, thought they detected the signature of gravitational waves in the faint echoes of Big Bang radiation – the so-called Cosmic Microwave Background. But on closer scrutiny that signature was lost in the dust of the Milky Way.

It's one thing to try and see the evidence of gravitational waves in the heavens. But if gravitational waves are rippling through the fabric of space-time, perhaps radiating out from a binary pulsar, we might be able to detect them directly on Earth.

Work on gravitational wave detectors has been in train for some 20 years now. The largest of these projects, known as LIGO (Laser Interferometer Gravitational Wave Observatory), has been operating since 2002. LIGO consists of two L-shaped detectors, four kilometres on each side. Both are in remote areas, one in a shrubby expanse near Hanford in Washington state; the other 3,000 kilometres away in the swamps west of Baton Rouge, Louisiana. Two sets of detectors are crucial to rule out rogue signals. A truck rumbling

by in Hanford will set off the detector but if a real gravitational wave rolls by, it will set off Hanford, and then a 100th of a second later, Louisiana.

The passing gravitational wave will stretch and shrink space-time, causing each of LIGO's arms to stretch and shrink alternately by a vanishingly tiny amount (about one 10,000th the size of a proton). Laser beams mounted at the far end of each arm bounce back and forth between mirrors. Their light waves intersect at the corner of the "L". Normally they are perfectly out of phase – the peaks of one line up with the troughs of the other – so the signals cancel each other out. As soon as one arm changes length, the perfect cancellation is lost and you get a signal.

Other countries are also in the hunt. Italy, for instance, has the VIRGO detector, Australia is constructing AIGO (the Australian International Gravitational Observatory) in Western Australia and India is planning to build its INDIGO detector. There are also plans for a space-based satellite array: the pilot mission, LISA Pathfinder, is set for launch this September (LISA stands for Laser Interferometer Space Antenna).

This May, LIGO was upgraded to Advanced LIGO with its sensitivity increased 10-fold. Excitement is building, as physicists sense that Einstein's final prediction will soon be confirmed. LIGO spokesperson and physicist Gabriela González anticipates snagging a gravitational wave as early as 2017. Champagne won't suffice for *that* celebration, she says. "I think we'll want something more."

YET FOR ALL ITS TRIUMPHS, general relativity faces a couple of big challenges. Einstein wrestled unsuccessfully with one of them: reconciling the theory with its great nemesis, quantum mechanics. Each theory has been outstanding in its own domain – relativity in the cosmos, quantum mechanics in the subatomic world. But occasionally the domains overlap. To understand the Universe's earliest moments, as well as the insides of black holes, we still need a theory that bridges the very large and the very small.

No one knows what the resulting theory might look like. One candidate is string theory, based on the premise that the fundamental building blocks of the Universe are tiny strings. An alternative, "loop quantum gravity" views space-time as granular. As with string theory, however, its proponents have yet to come up with an experiment to test it.

And then there's the problem of dark energy. Discovered in the late 1990s it appears to be a force that acts in opposition to gravity, causing our Universe to expand at an accelerating rate. The Universe, it seems, obeys two masters – gravity and dark energy – and it may take another Einstein to make sense of the latter.

Will all this require a modification of Einstein's masterpiece?

No, says Clifford Will. Fiddling with general relativity, he believes, would be tantamount to changing the Fifth Symphony. "General relativity is so unbelievably beautiful and simple – it's in some ways the most perfect gravitational theory that you could possibly imagine," he says. All of the alternatives he's seen so far are "horrendously ugly by comparison".

And so Einstein's theory, like a Beethoven symphony, remains with us, 100 years on. We want to go further, but that would mean adding a violin theme here or dropping a few cello notes there; perhaps even writing a whole new movement – and that would mean messing with perfection.

"My personal view," says Will, is that "whatever's going on with black holes or dark energy – at the end of the day, I think general relativity will survive".

DAN FALK is a science journalist based in Toronto. His books include *The Science of Shakespeare* and *In Search of Time*.

ILLUSTRATIONS
Jeffrey Phillips

GHOST TRAPS

We have no idea what most of the matter in the Universe is made of. Are we finally closing in on dark matter? ROBIN McKIE reports.

→

DARKSIDE-50: a subterranean vat of liquid argon in Italy's Gran Sasso Laboratory is one type of dark matter trap. But multiple strategies are being deployed.

01

IF YOU WERE DESIGNING a villain's lair for a James Bond movie, you would be hard pushed to create one as spectacular as Italy's Gran Sasso Laboratory.

SOMETHING ELSE WAS GLUEING THE GALAXY TOGETHER.

TO REACH IT, you follow the A24 motorway west towards Rome as it plunges through a 10-kilometre tunnel drilled below the Gran Sasso National Park, a mountain range that is home to bears, wildcats, wolves, chamois and thousands of summer tourists.

Half way along, an unsigned tunnel branches to the right. Travel 100 metres along this passageway and you reach a four-metre high, solid stainless steel door topped with barbed wire. As it swings open, a labyrinth of tunnels, uniformed guards and glittering racks of equipment appear before you. All the scene lacks is the appearance of a mysterious figure, clutching a white Persian cat, to let you know: "We've been expecting you, Mr Bond."

You won't find a Bond villain down here. But you will find physicists, burrowed under the mountains in their hunt for dark matter. This elusive material makes up 85% of the matter in the Universe. We know it must be out there – without it galaxies would fly apart and we would not exist. But so far what it's made of remains a mystery; we've been unable to detect the stuff.

That is about to change. Researchers working in several scientific arenas – including Gran Sasso – are now confident that within the next two or three years they will make the breakthrough that will reveal the truth about dark matter.

"THERE ARE TWO WAYS we're likely to succeed," says Chamkaur Ghag, who leads the "direct" dark matter search at University College London. Direct searches involve placing detectors deep underground at places such as Gran Sasso. Here 1,400 metres of rock shelters the detectors from the cacophony of particles pelting the Earth's surface. If the physicists pick up any hint of a signal way down there, "we will know we have hit pay dirt", Ghag says.

The other method of revealing dark matter is more dramatic. Scientists believe they should soon be able to make the invisible material inside the world's most powerful atom-smasher, the Large Hadron Collider at the European Organisation for Nuclear Research (CERN), near Geneva. The collider recently reopened with double the power it employed during its successful hunt for the Higgs boson. Since matter and energy are interchangeable, at these massive energies particles can be created.

More power means a greater chance of creating more massive particles – possibly dark ones. It also creates more interactions so if the creation of dark matter is extremely rare, the chances of picking it up are greater.

"I would have thought that if dark matter exists we will be well placed to make it at CERN in the very near future," says John Ellis, one of the organisation's key theoretical physicists. The dark matter will be detected at CERN by its absence – the energy and mass that is missing after physicists account for all the particles in the debris of smashed protons.

Who is likely to get there first? Will it be the subterranean teams manning underground detectors in their lairs, or will it be the collider physicists smashing protons into each other?

"It's going to be a very close call," admits Ghag, who previously worked on the XENON100 and DarkSide-50 projects at Gran Sasso and now works at a similar facility called SURF (the Sanford Underground Research Facility) in the US. "But even if CERN gets there before us, we would still need to confirm with direct detection that the particle they make is entirely responsible for all dark matter," he says. The CERN result – which will narrow down the energy and mass of the dark particle – would "indicate we are on the right track and are closing in on our target", he says.

THE STORY OF DARK MATTER goes back to the first half of the 20th century when astronomers realised galaxies were spinning so fast that they should have flung themselves apart.

Think of a stone tied to a piece of string. If the string is too weak, when you whizz it round your head it will snap and your stone will hurtle into the

distance. And so it is with galaxies. A galaxy needs a great deal of mass to generate a gravitational field powerful enough to hold on to its rapidly rotating stars. In 1932, Dutch astronomer Jan Oort pointed his optical telescope at the Milky Way and from its luminosity and redshift (a way of measuring how fast stars are receding), estimated the mass and rotation speed of the stars. He concluded there were too few stars to glue the spinning galaxy together.

A year later, Fritz Zwicky at the California Institute of Technology reported a similar conundrum while observing a large group of galaxies known as the Coma Cluster. At their speed of rotation, the outer galaxies ought to have been flung out. Oort and Zwicky referred to the missing galactic material as “dark matter”.

The idea that some exotic form of invisible matter existed was hotly contested. Surely it could be explained by the inability of light telescopes to detect faint galactic objects. There was no shortage of mundane candidates: tiny stars, large dark neutron stars, brown dwarfs (small failed stars) or clouds of diffuse gas.

But the idea of dark matter refused to go away. In the 1970s Vera Rubin and colleagues at the Carnegie Institution of Washington made more rigorous measurements of the rotation speeds and matter content of a number of galaxies. In every galaxy measured, there were far too few stars to account for the speed of the galaxy’s rotation. Something else was generating a powerful gravitational field that held each galaxy together.

In subsequent decades, astrophysicists have eliminated virtually all the mundane candidates for dark matter. Spinning neutron stars were detected by their radio waves. Infrared detectors picked up dim stars and brown dwarfs. And space-based telescopes such as NASA’s Chandra X-ray Observatory measured the vast mass of gas clouds, such as the one that engulfs our Milky Way and weighs as much as all the stars inside. Yet when all the dim and ethereal matter is added up, it is still not enough to glue galaxies together.

“We’ve spent more than 30 years trying to pin down objects that might account for dark matter, and have had no success,” says astrophysicist Gerry Gilmore of Cambridge University.

Other evidence for dark matter comes from gravitational “lensing”. Sometimes, as a galaxy spins through an apparently empty stretch of space, multiple images appear – as if it were passing behind a warped lens. The lens in this case is inferred to be dark matter: its gravity is warping the fabric of space.

But the strongest evidence for dark matter “is that we’re here at all”, says Alan Duffy, a theoretical physicist at Melbourne’s Swinburne University of Technology. His supercomputer-based models of the formation of the Universe show that the plasma created by the Big Bang was too hot and too smoothly distributed to have collapsed into galaxies 13 billion years later.

But dark matter is not subject to the same frenetic interactions. It would have settled down early on, forming “wells” that ordinary detectable matter – also known as baryonic matter – could fall into.

Having ruled out baryonic matter as the source of the missing mass, the only remaining option was that dark matter is composed of an exotic subatomic particle. It is also abundant: five times more plentiful than the baryonic matter scattered throughout the Universe.

Physicists took to calling these numerous but mysterious bits of matter *weakly interacting massive particles* – or WIMPS.

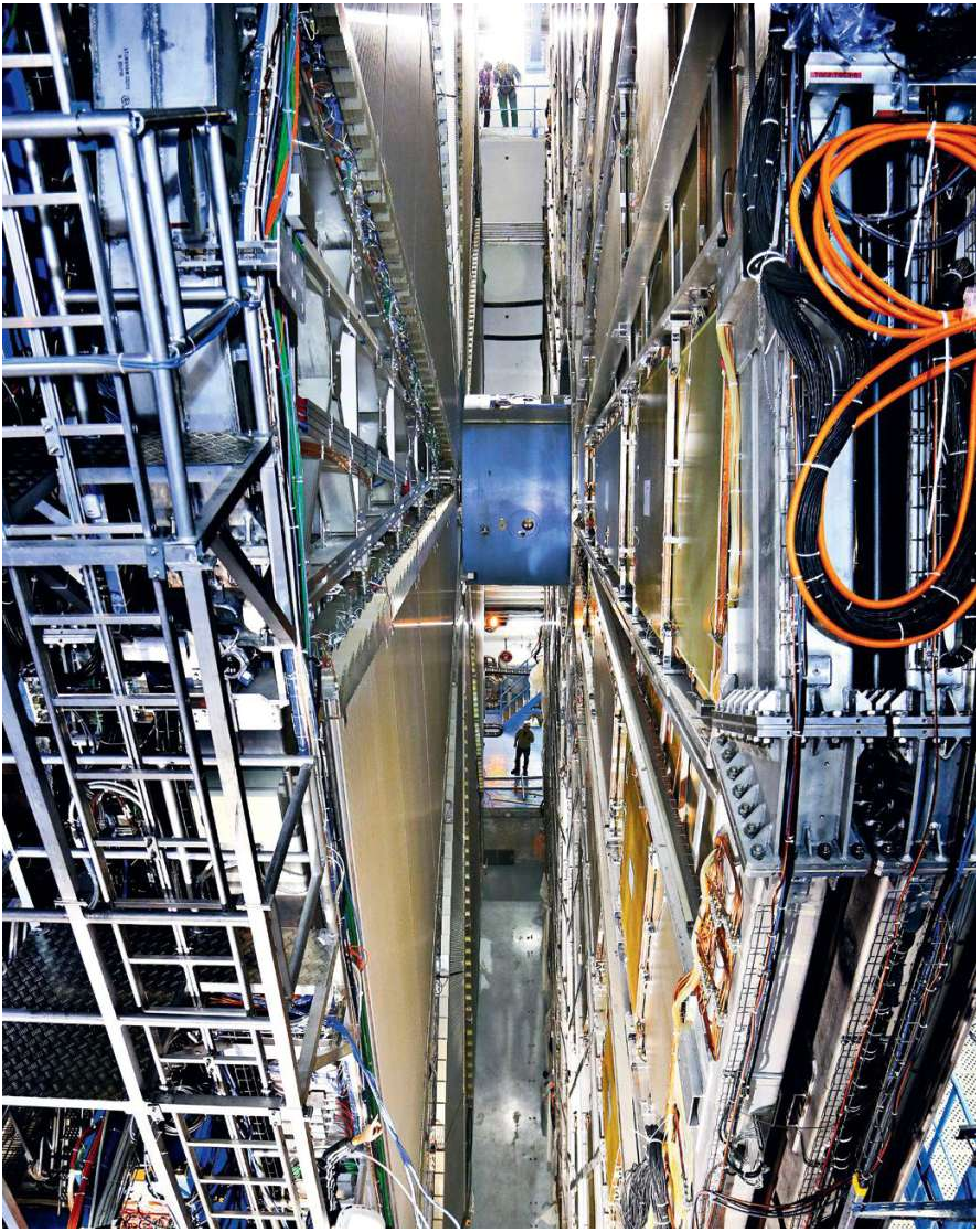
02

In the tunnels under Gran Sasso mountain lie several traps for dark matter.

So how are we to detect a WIMP? Via one of the fundamental forces. There are four: gravity; the electromagnetic force; the strong nuclear force that glues the nuclei of atoms together; and the weak nuclear force that transforms particles from one type to another and drives radioactive decay.

Scientists have ruled out the idea that dark matter interacts in any way with either electromagnetism or the strong nuclear force. “If it did we would have seen the results – bursts of light or radiation,” says Ghag. These would be produced

03



The Large Hadron Collider under Geneva was shut down for two years and upgraded to increase its energy by 60%. Scientists hope some of this energy will be converted into dark matter.

whenever dark matter and regular matter particles collide.

We know dark matter *does* interact with gravity. But gravity exerts a virtually undetectable force at subatomic scales. For an electron and proton, the gravitational force is 39 orders of magnitude weaker than the electromagnetic force – so gravity is not a helpful way to detect a dark matter particle.

That means all our hopes are pinned on the last remaining force, the weak force. "And that is what we really mean when we call them weakly interacting massive particles – it's because they may interact with the weak force," says Ghag.

Space must be saturated with WIMPS. Katherine Freese, a theoretical physicist at Michigan University and author of *The Cosmic Cocktail: Three Parts Dark Matter*, believes billions of these particles must pass through the human body every second – rather like neutrinos. Indeed neutrinos seem to fit the bill for dark matter since they have mass but only interact via the weak force. But they cannot account for dark matter. Although they are the most abundant particle in the cosmos – with one billion cosmic neutrinos for every atom – their mass is less than a billionth the mass of a proton. They are far too light to account for the missing mass in the Universe.

HUNTING FOR WIMPS has been "like searching for a particular kind of fish in the ocean", says the slim, amiable Ghag, with his typical rapid-fire verbal delivery. "At first, you put on goggles and dive down just below the surface to see if you can see it. If that does not work, you try scuba gear and go deeper. Then you try a submarine until, eventually, you find it." Or so he hopes.

Hence the detectors installed under Gran Sasso and at several other underground laboratories have been built thousands of feet below the surface, usually in old mines. These include the Stawell gold mine near the Grampians National Park in Victoria, Australia; the old Homestake gold mine in South Dakota; and the Boulby salt mine in north England.

The subterranean locations are important. The Earth's surface is bombarded by sub-atomic particles called muons. These energetic, charged particles are the byproducts of high-energy cosmic rays which slam into our atmosphere so hard they smash oxygen, nitrogen and other atmospheric gases into showers of subatomic particles. "Muons light up our detectors like Christmas trees," says Ghag. "They are so numerous they would blind us to anything else."

Down in Gran Sasso, shielded by 1,400 metres of rock, muon levels are one million times lower than at the surface. More of them are filtered out by placing the particle detectors in huge vats containing thousands of cubic metres of pure water. Inside the tank, a huge sphere containing a device called a scintillator is used to cut out any stray particles that make it through the water jacket. "We are putting one device inside another like a set of Russian dolls to get rid of every possible spurious signal," says Frank Calaprice of Princeton University, who co-leads the DarkSide-50 experiment at Gran Sasso.

The last Russian doll is a stainless steel sphere containing argon or xenon liquid, with some gas on top. If a WIMP passing through hits an argon or xenon atom directly, the weak nuclear interaction between atom and particle might bump out an electron or spit out a photon. The characteristics of that signal will tell scientists if a muon has slipped through the screens or whether they have actually detected a WIMP.

To date, despite some tantalising signals at detectors such as DAMA [see box, page 69], physicists are yet to be convinced that any WIMP has announced its existence. While researchers are continually refining the sensitivities of their machines, it is possible that we will *never* catch a WIMP. Sadly (for all the billions spent on the detectors) it may be that dark matter does not interact via any of the known forces other than gravity. "One way or other, we are going to find out very soon if that is the case," says Ghag.

GRAN SASSO'S DETECTORS might never trap a WIMP. But scientists at CERN are confident they can create dark matter.

For a start, their base of operations utterly dwarfs those at Gran Sasso or South Dakota's Homestake mine. CERN is a sprawling suburb of Geneva stacked with laboratories, dormitories, restaurants and control rooms all built over a giant circular tunnel, 27 kilometres in circumference, that makes up the Large Hadron Collider.

The collider is roughly the size of the London Underground's Circle Line, and has been constructed with nanometre precision. Its magnets – which guide beams of protons round its tunnel – are chilled to within two degrees above absolute zero (a temperature at which electricity flows without resistance), making the collider the coldest place on Earth. At the same time, the tube that carries those beams of protons has been sucked of virtually every atom or molecule, creating a vacuum that is purer than that found in space.

THE GRAVITY OF DARK MATTER IS WARPING THE FABRIC OF SPACE.

A CLOSER LOOK

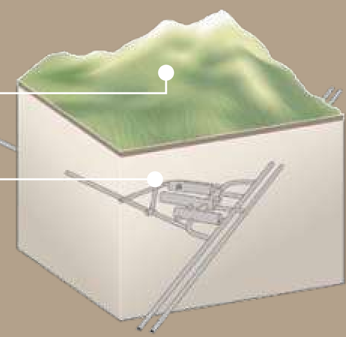
TWO WAYS TO SEARCH FOR DARK MATTER

DARKSIDE-50

Scientists at Gran Sasso hope to identify dark matter particles as they pass through their DarkSide-50 detector. To be sure they've detected dark matter, scientists must filter out all other particles, hence the detector's Russian doll-like structure. Muons and neutrons are screened out by tanks filled with ultrapure water and scintillator fluid.

Gran Sasso, Abruzzo, Italy

DarkSide-50, 1.4 kilometre depth

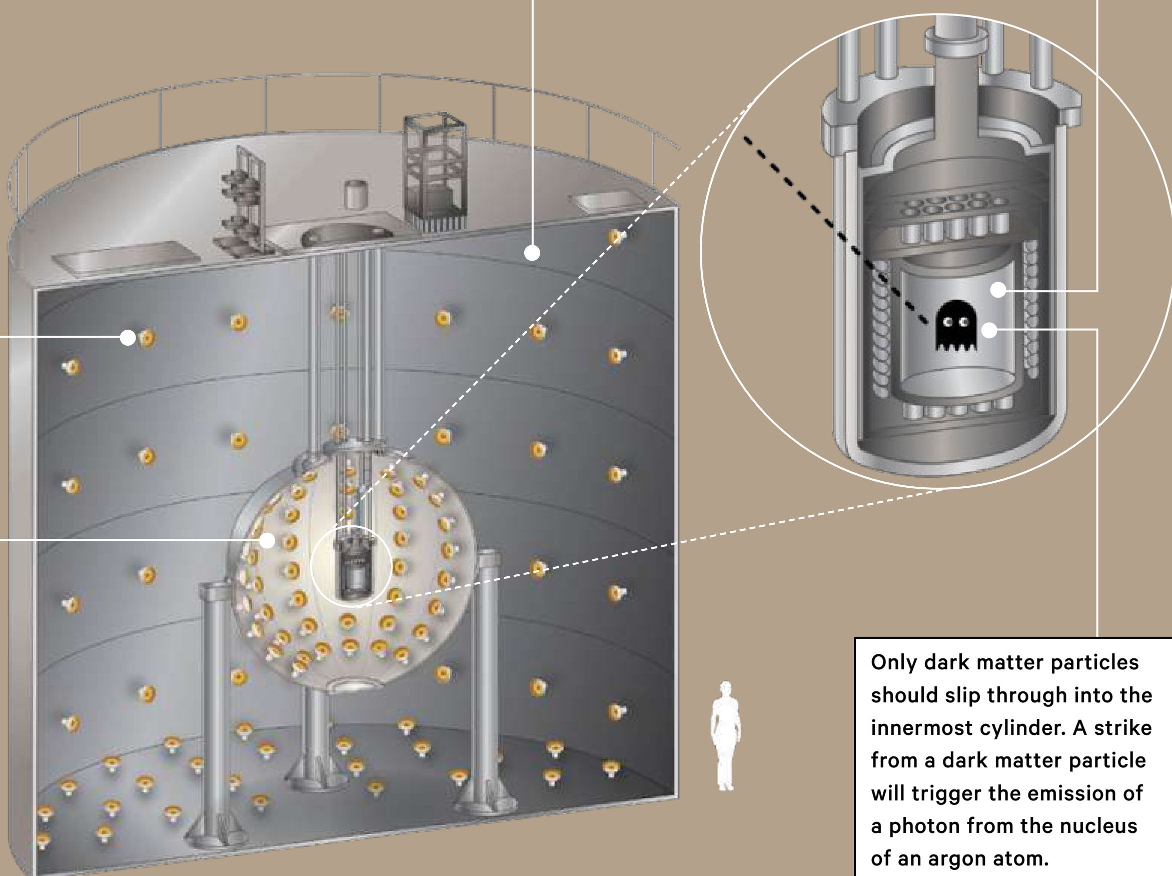


Outer tank filled with 100,000 litres of ultrapure water.

Detector tank filled with 50 kilograms of liquid argon

Photodetectors look for a flash of light released when a dark matter particle bumps an atom.

Inner tank filled with 26,000 litres of scintillator fluid.

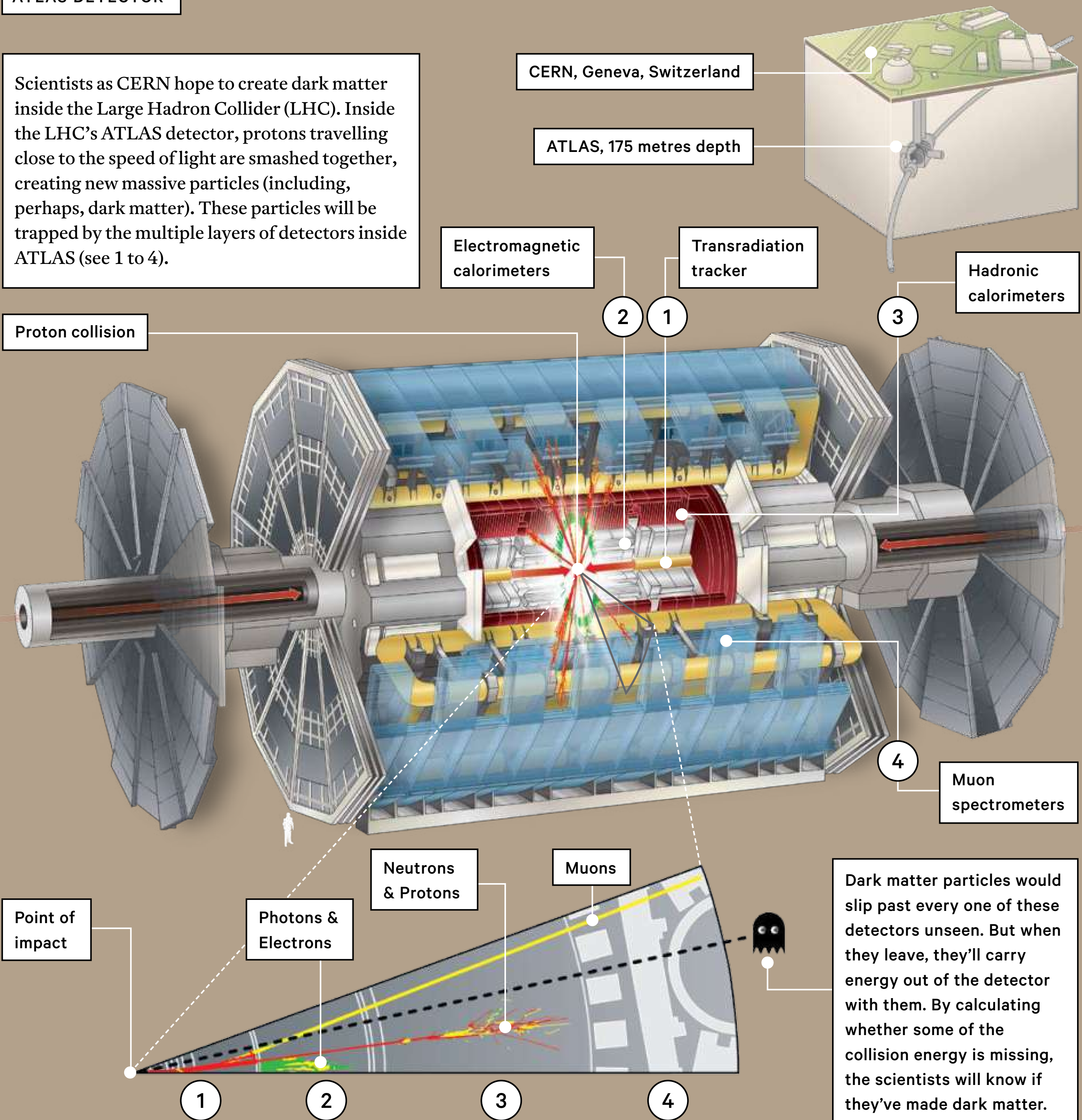


Only dark matter particles should slip through into the innermost cylinder. A strike from a dark matter particle will trigger the emission of a photon from the nucleus of an argon atom.

04

ATLAS DETECTOR

Scientists as CERN hope to create dark matter inside the Large Hadron Collider (LHC). Inside the LHC's ATLAS detector, protons travelling close to the speed of light are smashed together, creating new massive particles (including, perhaps, dark matter). These particles will be trapped by the multiple layers of detectors inside ATLAS (see 1 to 4).



Dark matter particles would slip past every one of these detectors unseen. But when they leave, they'll carry energy out of the detector with them. By calculating whether some of the collision energy is missing, the scientists will know if they've made dark matter.

Three years ago, CERN scientists used their astonishingly powerful and precise instrument to discover the Higgs boson. Then they shut down for two years to upgrade the machine. The LHC "is almost like a new machine now", says CERN's Frederick Bordry, director of accelerators and technology.

When it discovered the Higgs, the LHC could generate energy bursts of up to eight trillion electron volts (8 TeV). Now, it can produce collisions with energies of up to 13 TeV.

The more energy, the more likely this matter-energy soup will create new massive particles. Just as two protons collided with enough energy to form the Higgs boson – with far more than twice the mass-energy of two protons – the hope is the higher energy will create a massive dark matter particle.

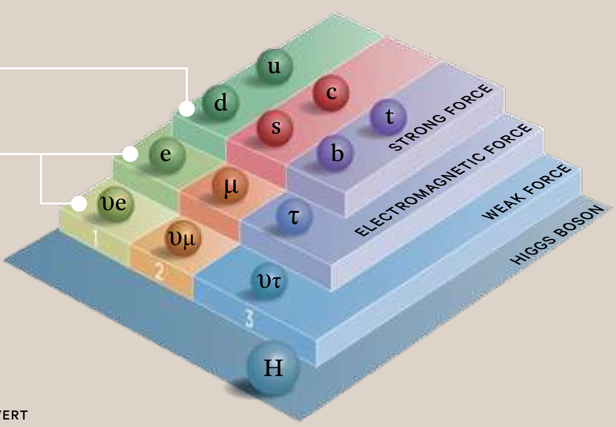
"When we batter the beams of protons into each other, we will make particles of a mass we think could be similar to those that we think account for dark matter," says John Ellis, one of CERN's key theorists.

Ellis has been hunting for dark matter all his working life, albeit indirectly at first. He is an amiable, slightly shambolic figure with a massive white beard, who has been compared to Santa Claus, Dumbledore and Gandalf.

A Cambridge University graduate, Ellis began his research on supersymmetry in the early 1970s. Supersymmetry predicts that versions of the particles that make up normal matter possess mirror, or "supersymmetrical", versions.

THE STANDARD MODEL

PHYSICISTS ORGANISE subatomic particles into the Standard Model (shown). Perhaps "supersymmetrical" equivalents to these particles might account for dark matter.



CREDIT: ANTHONY CALVERT

Thus there could be supersymmetrical quarks – or squarks – out there. Or supersymmetrical electrons – selectrons. Ellis's field became embroiled in the hunt for dark matter when physicists realised some types of supersymmetrical particles and WIMPS could be one and the same.

If the Large Hadron Collider wins the battle to find these elusive entities, it will be a fitting tribute to Ellis who has directed much of CERN's research effort over the past couple of decades. These efforts have revealed the nature of the Standard Model of Matter [see diagram], which could finally be completed by incorporating the ideas of supersymmetry.

Most CERN physicists believe supersymmetrical particles – and therefore, WIMPS – are likely to lie within the range of the upgraded collider. As Dave Charlton, head of the collider's ATLAS detector, puts it: "The supersymmetry particles that we think we will soon be producing provide a perfectly natural explanation for dark matter – in the form of WIMPS." He predicts that "the next couple of years promise to be extremely interesting".

Because dark matter rarely interacts with regular matter, it won't appear directly in the collider's detectors, Ellis explains. "If WIMPS are created ... they will escape through the collider's detectors unnoticed." But when they go, they will carry away energy and momentum with them. "We will be to able to infer their existence from the amount of energy and momentum missing after a collision."

But there's no guarantee says Duffy. "The collider might not be capable of producing a dark matter particle, regardless of the energies it reaches. And if it does, it has to make enough to notice that some matter is missin"

So who will be the first to snare these ghostly particles? Duffy has no qualms about backing the physicists at Gran Sasso. "It's a race. But just like the tortoise and the hare, I'd rather go with the slower, surer runner."

ROBIN MCKIE is science editor of *The Observer* newspaper in London. He was voted Science and Technology writer of the year in the UK in 2013.

IMAGES
01 Franco Fasciolo
02 Franco Fasciolo
03 Claudia Marcelloni De Oliveira / CERN
04 Anthony Calvert

STRIKING DARK MATTER IN AN AUSSIE GOLD MINE

THE RESIDENTS OF THE VICTORIAN country town of Stawell are a resourceful lot. The town was founded in the 1853 gold rush and has long been sustained by gold. But as profits dwindle, the mine is being revived in a remarkable way: by hunting for dark matter.

The 10,000 residents of Stawell may not be particle physicists but they have been quick to realise their mine's potential.

"The next chapter in Stawell's story is an exciting one, home to hundreds more local jobs and, possibly, the world's next great scientific discovery," enthused Victorian Premier Daniel Andrews last February as he announced his State Government would invest $1.75 million to kickstart the gold mine's conversion. The Federal Government matched the funding, and the Australian Research Council contributed $1.18 million.

The funding is remarkable given how difficult it has been of late to extract any government money for new science projects. Clearly resuscitating regional towns is good politics. And Melbourne University's particle physicists have also made a persuasive argument.

"For a few million, this is a cheap Nobel prize," says physicist Elisabetta Barberio, in charge of building the detector at the bottom of the kilometre-deep gold mine. After decades of hunting, dark matter might finally be captured here.

So why is Stawell so significant? Barberio and her colleagues jumped at the opportunity because hunting for dark matter in the Southern Hemisphere might resolve a scientific impasse.

Theory tells us the Universe contains five times more dark matter than the ordinary atoms surrounding us. "Here, right in the space between you and I, could be this alternative world of dark matter," says the otherwise sane-seeming Geoff Taylor, director of the Centre of Excellence for Particle Physics at the University of Melbourne.

Particle physicists joined the hunt for the ghostly stuff in the 1990s, building detectors that rely on the hope that when a dark matter particle – or weakly interacting massive particle (WIMP) – bumps into an atom's nucleus, it gives it a glancing blow, rather like a gentle cue ball. The WIMP slips off in its ghostly way while the recoiling nucleus emits a photon.

Difficulties arise because many things can interact with an atom and cause a photon to be emitted. The trick is to eliminate as many of these pretenders as possible. So detectors are located deep underground to shield them from space muons and surrounded by multiple screens to protect them from rock-borne radioactive particles.

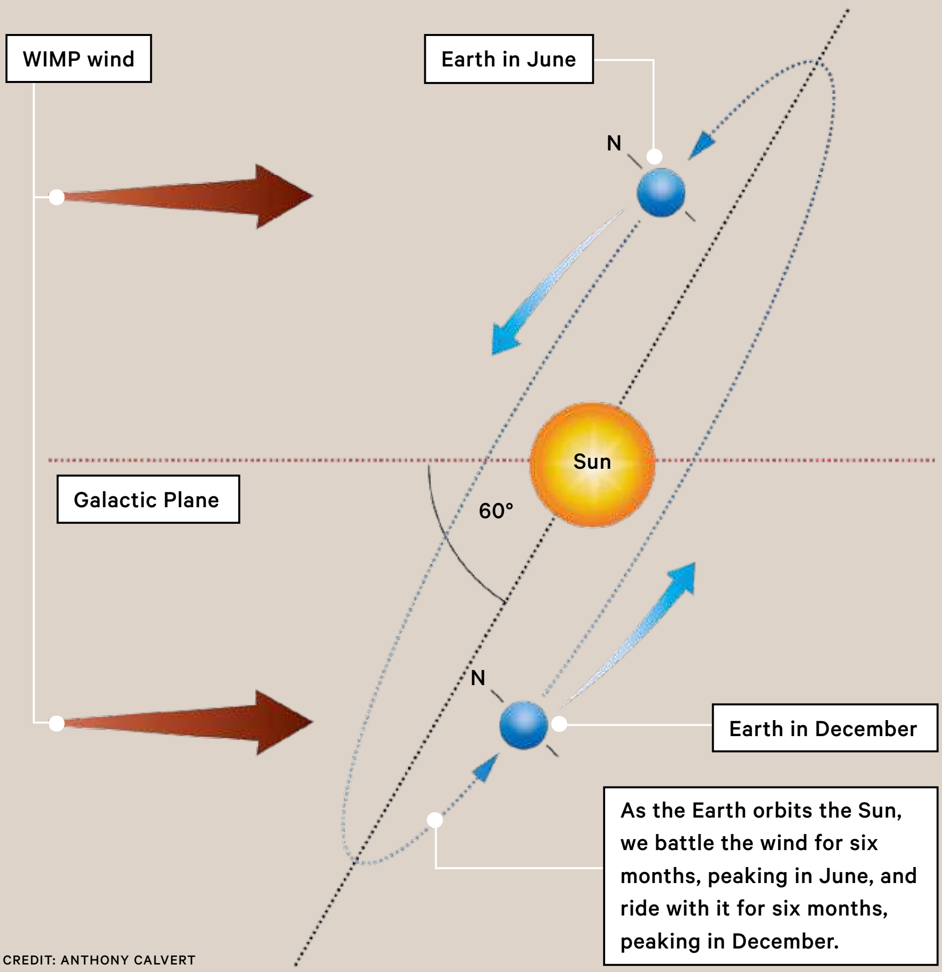
Many detector designs have been tried. Different types of traps are a good strategy, says Barberio, since "we don't really know what we're looking for". The main requirement is that detector materials be extremely pure to eliminate radioactive noise. The first models used →

Stawell gold mine might finally solve the riddle of dark matter.

CREDIT: MICHAEL SLEZAK

THE WIMP WIND

PHYSICISTS BELIEVE the Milky Way is surrounded by dark matter particles – WIMPS. As the Sun hurtles through the galactic plane at 220 kilometres per second, the drag creates a WIMP wind.



CREDIT: ANTHONY CALVERT

→ pure crystals of sodium iodide (NaI). Later generations used liquefied xenon, at first containing modest amounts because it was expensive to produce. XENON100 at Gran Sasso now contains 100 kilograms, while the Large Underground Detector Dark Matter Experiment (LUX) at a mine in South Dakota contains 350 kilograms – and they're heading to seven tonnes in South Dakota with the Lux-Zeplin (LZ) detector. The more xenon, the more shielded the core of the detector, and the greater the sensitivity. Argon detectors such as DarkSide-50 are also being tried, but so far have yet to match the quiet background and sensitivity delivered by xenon.

Despite dozens of experiments most detectors have failed. A notable exception is DAMA (DArk MAtter) at Gran Sasso. It was one of the first detectors, and in 1998 it detected *something*.

It has continued to detect that signal with ever greater statistical significance (now with nine standard deviations) even though the XENON100 detector, in the same location and with more than 1,000 times greater sensitivity, has not.

Many physicists have concluded DAMA is detecting some sort of artefact. On the other hand, perhaps DAMA happens to have the right sort of trap? Even Chamkaur Ghag, a dark matter hunter and DAMA sceptic at University College London, acknowledges, "they do have spectacularly good crystals".

To find out if the ultrapure NaI crystals are the right trap for dark matter, other traps need to incorporate crystals of this quality and replicate the experiment. That's what will happen at Stawell and Gran Sasso, when identical twin detectors are placed in these locations as part of an international project dubbed SABRE and headed by Frank Calaprice from Princeton University.

So why is Stawell the linchpin?

As our Sun zooms though the Milky Way at 220 kilometres per second, it is thought to encounter a stream of dark matter particles known as the WIMP wind. For half the year, Earth's orbital motion around the Sun means the two sail *into* the wind together.

But for the other half of the year, Earth tacks back around the Sun and sails *with* the wind. The prediction then, is that the Earth will be battered by WIMPs while sailing into the wind, and experience relative calm while sailing with it. This could be what DAMA measures: its signal peaks around June and is weakest around December.

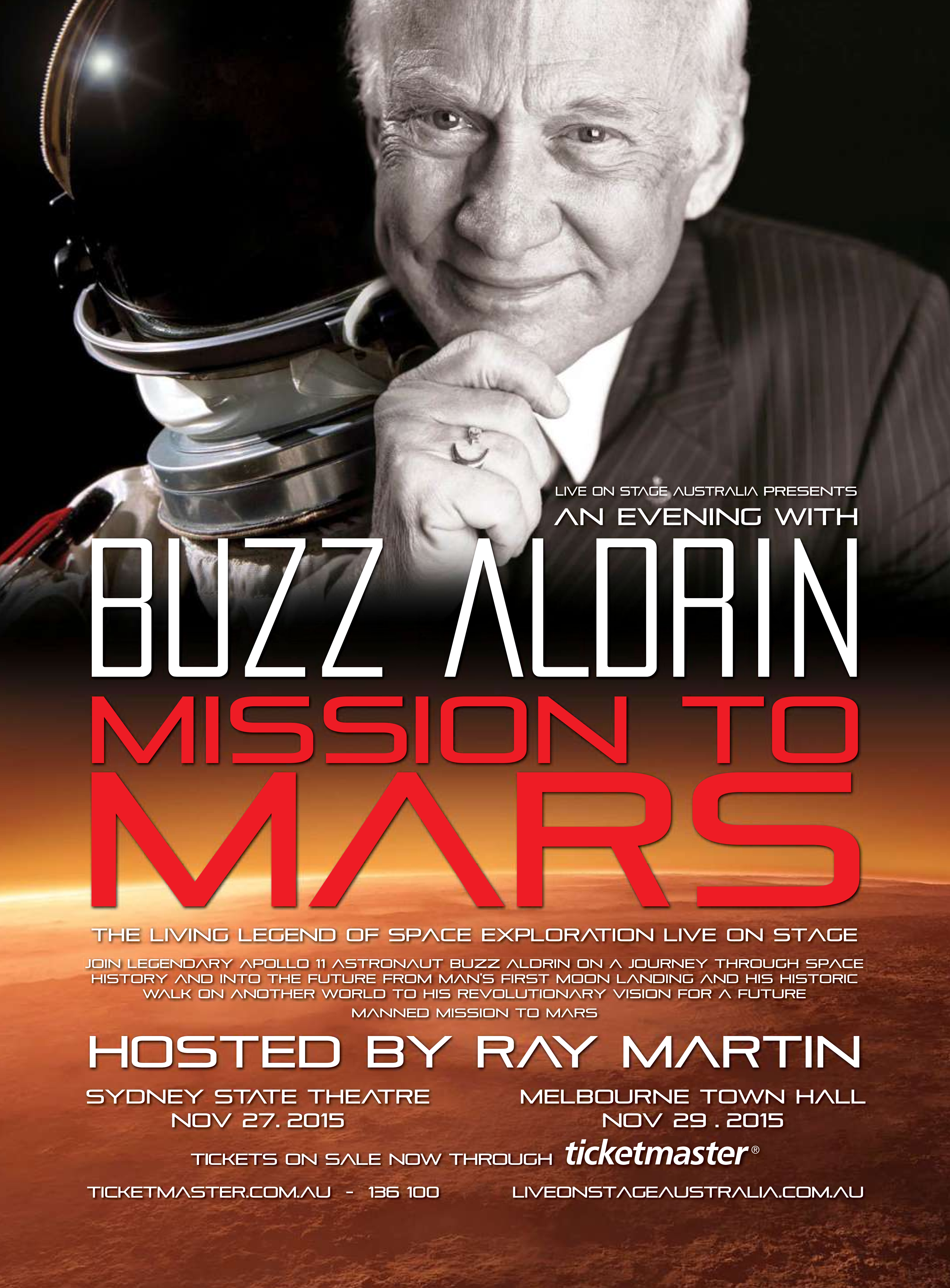
But there's a problem: these fluctuations also correspond to the Northern Hemisphere summer and winter: Earth's atmosphere is thicker in the summer and generates more muons than in winter. So is DAMA merely detecting summer muons, or the WIMP wind? The debate has raged for years.

Scientists hope an identical detector in the Southern Hemisphere will resolve it. If the Gran Sasso detector is truly identifying changes in the WIMP wind then the Southern Hemisphere detector will feel the same effect at the same time.

But if the seasons are the explanation, then the Stawell detector should see the opposite fluctuation to its Northern Hemisphere twin.

Meanwhile, the good people of Stawell need to be patient about their Nobel. The detector should take five years to build and the results should be in hand three to five years after that.

— ELIZABETH FINKEL


LIVE ON STAGE AUSTRALIA PRESENTS
AN EVENING WITH
BUZZ ALDRIN
MISSION TO MARS
THE LIVING LEGEND OF SPACE EXPLORATION LIVE ON STAGE
JOIN LEGENDARY APOLLO 11 ASTRONAUT BUZZ ALDRIN ON A JOURNEY THROUGH SPACE HISTORY AND INTO THE FUTURE FROM MAN'S FIRST MOON LANDING AND HIS HISTORIC WALK ON ANOTHER WORLD TO HIS REVOLUTIONARY VISION FOR A FUTURE MANNED MISSION TO MARS
HOSTED BY RAY MARTIN
SYDNEY STATE THEATRE
NOV 27. 2015
MELBOURNE TOWN HALL
NOV 29 . 2015
TICKETS ON SALE NOW THROUGH ticketmaster®
TICKETMASTER.COM.AU - 136 100
LIVEONSTAGEAUSTRALIA.COM.AU

EPOCH OF THE INVISIBLE MAN

As far back as Plato people imagined the power of invisibility. Now the fantasy is being made real. PHILIP BALL reports.

01

A MYSTERIOUS VISITOR APPEARS in the sleepy English village of Iping with bandages around his face, dark glasses, a false nose and wig. To their horror, the villagers soon discover that the man underneath all these layers is totally invisible.

DEVICES SEEM TO MAKE FISH, CATS AND EVEN PEOPLE VANISH.

HE IS A MEDICAL STUDENT who discovered the secret of invisibility by performing experiments on himself – and does not know how to reverse the process.

As Griffin, the antihero of H. G. Wells' 1897 novel *The Invisible Man*, grows more desperate, he terrorises the villagers. The situation goes from bad to worse, as he descends into a homicidal fury and plans world domination. "This is day one of year one of the new epoch," he declares "the epoch of the invisible man".

In fiction, power corrupts, but invisibility corrupts absolutely. The trope goes back to Plato. In one of his myths, a magical ring that confers invisibility tempts the shepherd Gyges to kill the king of Lydia, seduce his queen, and set himself up as the kingdom's new ruler. Despite the philospher's warning, our fascination with invisibility has not waned. Now science is starting to make it possible.

Over the past decade researchers have developed cloaks, shields and other devices that seem to make fish, cats and even people vanish. Spinoff technologies could shield objects from sonar, radar and our sense of touch. They might even protect buildings from earthquake shock waves.

But if we are really embarking on the epoch of the invisible man, we might want to listen to what Plato and H. G. Wells were telling us.

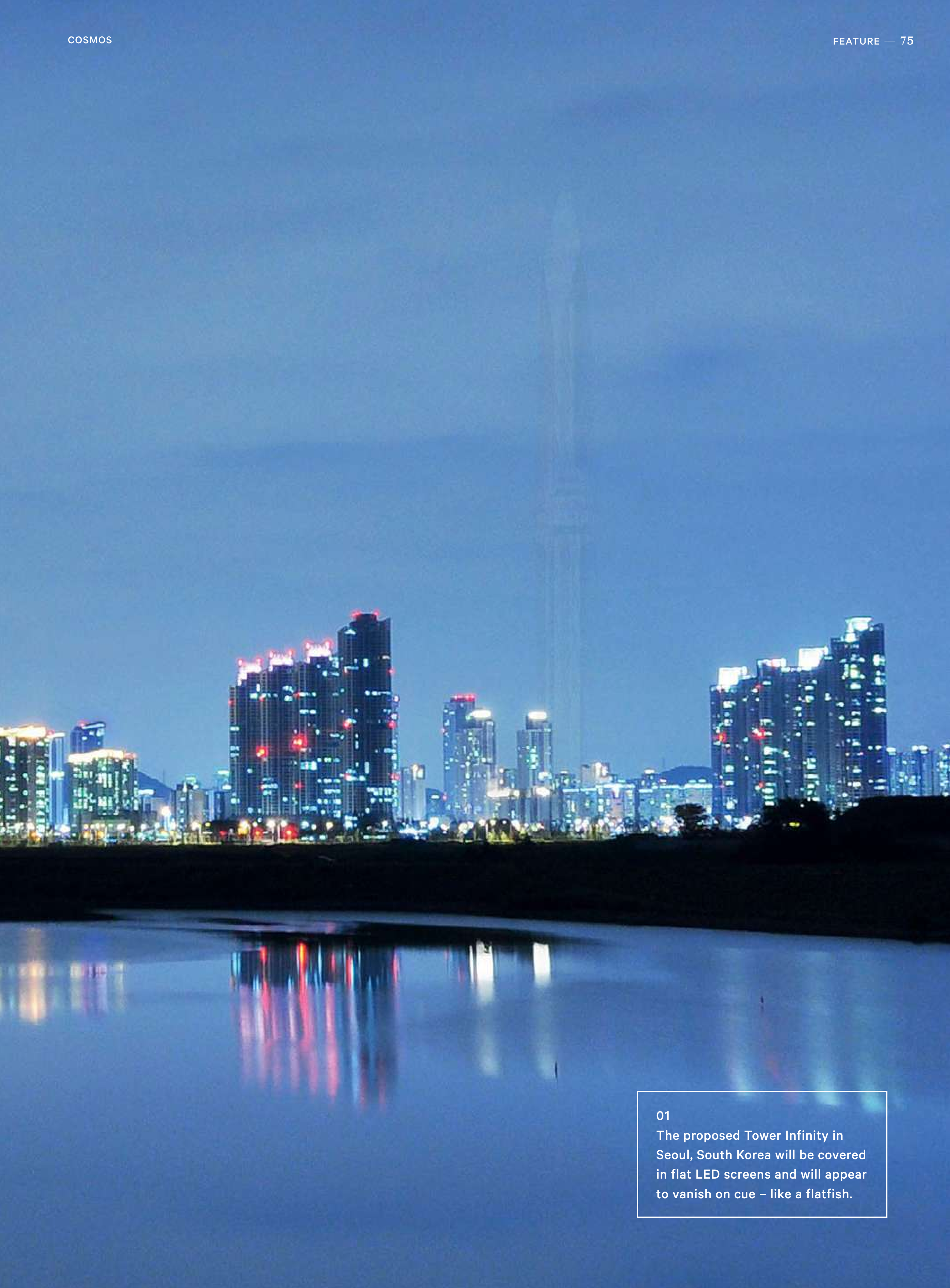
AS A PREDATOR APPROACHES, a flatfish lies still near the sea bottom, its skin almost indistinguishable from the sea floor. These creatures are among a select bunch, including octopuses and squid, that use adaptive camouflage to achieve a kind of invisibility. When a flatfish sees a mottled, brown sea floor, cells in its visual cortex signal other brain cells. These in turn signal skin cells to alter their pigmentation or reflective properties to blend in.

A flatfish-like strategy is behind one of the more ambitious attempts at invisibility – a planned 450-metre skyscraper called Tower Infinity in Seoul, South Korea, that will seemingly disappear on cue. A US-based architecture firm plans to cover the tower with flat LED screens. Like the flatfish's eyes, video cameras mounted up and down the tower's exterior will record the scene around it. The screens will display what the cameras "see", making the tower fade out of sight – at least when seen from the right distance.

The flatfish technique is also being used to hide people. In a much-viewed YouTube demonstration, a man wearing an "invisibility" cloak stands in front of the camera on a busy Japanese street. Passing pedestrians, trucks and buses are visible right through him. The hooded cloak is thickly encrusted with tiny reflective glass beads that allow it to function as a projection screen. It was created by Japanese electronic engineer Susumu Tachi, now at the University of Tokyo.

Here's how it's done. Tachi and his colleagues rig up a video camera behind the cloaked figure that records the scene without the figure. The camera relays the signal to a projector in front of the cloak that casts the scene on to the cloak's coating, creating an image as bright as the day-lit scene around it – and a passable illusion of invisibility.

The technology might have some useful applications, Tachi says. For example, adorning a solid wall with a rectangle of the glass bead carpet, which Tachi calls "retro-reflectum", could simulate a window, giving residents of protected old buildings a view of sorts without knocking out any walls. And coating a car or truck interior with retro-reflectum and mounting cameras on the outside could give the driver 360-degree visibility.



01
The proposed Tower Infinity in Seoul, South Korea will be covered in flat LED screens and will appear to vanish on cue – like a flatfish.

03

Tachi's colleague Masahiko Inami in an "invisibility cloak", that appears transparent thanks to reflective beads that function as a projection screen.

04

The flatfish uses adaptive camouflage to achieve near-invisibility on the sea floor.

But the technique is cumbersome. Creating the background image on the cloak requires video cameras and projectors, and you only see it properly if you're standing in the right spot. So Tachi's technology could never let anyone walk unseen among us.

An invisibility cloak that uses a mobile version of the Tower Infinity approach would have a better chance. Such a cloak would have miniaturised video cameras and flexible, lightweight LEDs woven into its fabric. As the person moved around, the cloak's video cameras would record his surroundings, and the LEDs in the fabric would project an image.

Of course the flatfish achieves this feat rather more economically.

SOME RESEARCHERS are getting closer to Harry Potter's invisibility cloak by doing away with cameras and projection screens altogether. They are relying on materials that can bend light in ways the normal laws of optics would seem to prohibit.

The idea is to erase an object by diverting light rays around it and then restoring them to their original path. To an observer on the far side it looks as though the rays have travelled in a straight line through empty space. In 2006, physicist John Pendry of Imperial College in London and electronic engineer David Smith of Duke University independently reported blueprints for such a device. A few months later, Smith's team dazzled invisibility aficionados by building a prototype.

These devices employ "optical metamaterials", electrical components that relay light signals and bend light in unusual ways. When a light ray enters a conventional transparent material, such as glass, it veers (or refracts) somewhat but continues in the same general direction. The degree of bending is called the refractive index. In glass and other ordinary materials it's a positive number.

The optical metamaterial in Smith's prototype invisibility shield has a negative refractive index. This means that when a light ray enters, it bends the "wrong" way compared with what we're used to seeing, creating some bizarre optical effects. The properties that enable this behaviour also allow optical metamaterials, when properly chosen and arranged in space, to steer a light ray around an object in its path.

In the 1990s Pendry charted a course toward such metamaterials. The way he envisioned it, you could design the electrical components from ultrathin metal wires – a few atoms thick – that act as tiny receivers and antennae to guide light around an object. (The rule is that the transmitters need to be of the same dimensions as the wavelength of light they are guiding). The drawback is that working with such thin wires would have been extremely difficult.

So Smith, who was then at the University of California at San Diego, aimed for a more achievable target. Rather than guide light waves, he aimed for much larger microwaves. His team made their transmitters by bending ordinary wire into little loops, several millimetres in diameter. Making a whole array of such loops by hand was painstaking work for Smith's graduate students, but they managed to assemble them into the world's first metamaterial with a negative refractive index. Later, he and his co-workers made the process faster and easier by etching arrays of the loops and rings into the copper foil of printed circuit boards.

Smith's invisibility shield was a breakthrough – but it was still not Harry Potter's cloak. The shield itself was perfectly visible. And it was not diverting light waves but microwaves.

Making metamaterial objects invisible to the human eye will require microscopically small components – this is quite beyond today's fabrication methods. But in coming up with designs for invisibility shields, Pendry and, independently, physicist Ulf Leonhardt of the University of St Andrews in Scotland, developed a mathematical theory called "transformation optics". This describes how to reshape the trajectories of light rays. The theory suggested some easier alternatives for invisibility shields, if you didn't mind compromising on the cloaking you could achieve.

SOME RESEARCHERS ARE GETTING CLOSER TO HARRY POTTER'S INVISIBILITY CLOAK.

IN 2008 PENDRY and his student Jensen Li showed how to create a "carpet cloak". Imagine placing a box on the floor, then draping a regular carpet over it. You'd see a big hump in the fabric. The carpet cloak interacts with the light in such a way that the carpet appears to lie flat on the floor.

Researchers at the University of California at Berkeley, led by Xiang Zhang, built such a device that works for near-infrared light. They used a simple array of microscopic holes etched into silicon to make a carpet cloak with a tendency to bend light that varies from one part of the structure to another – the largest bends are just above the hump and mask its presence. The Berkeley team has since fashioned a similar cloak from a patterned piece of silicon nitride that works for visible light.

You can also make a similar, though cruder, kind of invisibility carpet from the transparent natural mineral calcite. It has the unusual property of bending light that strikes it from one direction more

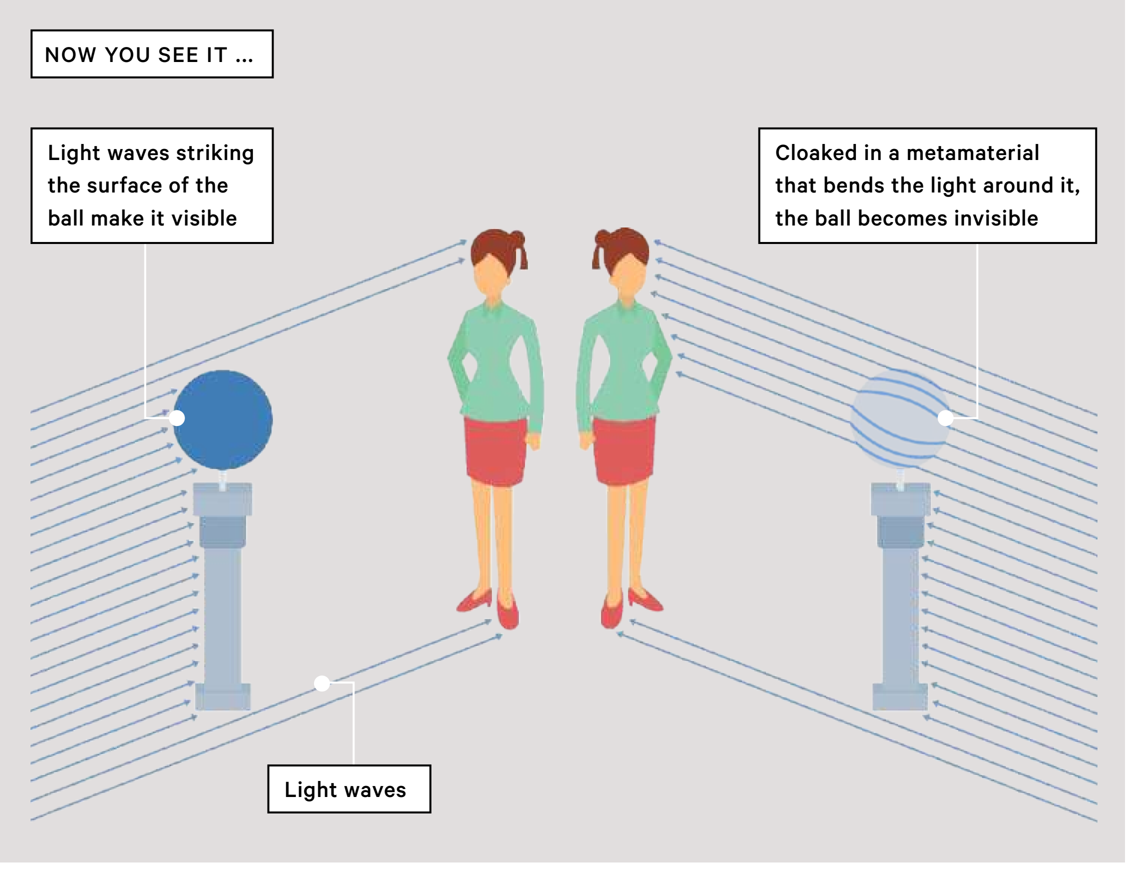
than light that strikes it from another direction. This property allows a cunning arrangement of specially shaped calcite prisms to bend light rays so that they appear to be bouncing off a flat surface beneath the prisms, thereby hiding a small cavity that contains an object. Although the shield does remain visible, much as an ordinary glass prism does, the objects within it do seem to vanish.

An even cruder, but still effective, invisibility shield relies on a special arrangement of high-quality optical-glass prisms to bend light around the central cavity. Again, the prisms themselves were visible, and the cloaking only works when viewing the device at eye level, rather than from above or below – but it does work, after a fashion. Built in 2013 by researchers at Zhejiang University in Hangzhou, China, the shield made a cat disappear (the feat reminiscent of *Alice in Wonderland's* Cheshire cat). When the Chinese feline investigated the cavity, any part of its body that passed inside seemed to vanish.

AS THEY EDGED CLOSER to invisibility, some scientists realised invisibility was just a start. That's because transformation optics is actually a general theory of how to manipulate waves, and as such it applies equally to, say, sound waves and even water and seismic waves. The theory has now led to a bevy of bizarre new devices. Transformation optics, Pendry says, "is galloping off in all directions. The fundamental theory is done and dusted, but there seems to be no end of new applications."

One application takes advantage of fogs. People moving though a fog appear as blurry shapes. But if their raincoats were made of the right kind of fabric, they might entirely disappear. When a light ray enters a fog, it bounces repeatedly off the droplets, making the light appear to come from all directions. Light does the same thing in frosted glass, where it bounces off bumps on the glass. In both cases this makes the outline of an object less distinct, but enough of the light still stays on course to make the object itself visible as a vague shadow.

It's possible to design a cloak that redirects the diffuse light enough to hide such shadows fully. The trick is to adjust the amount of light scattering in this sort of misty medium, so that the mist looks equally bright everywhere, rendering the object invisible. Physicist Martin Wegener of the Karlsruhe Institute of Technology in Germany and co-workers demonstrated this approach with cylindrical and spherical cloaking shells made from



a transparent plastic that contain dispersed small particles that scatter light. The shell and its contents seemed to disappear when placed into a tank of water made misty by adding dilute white paint.

Another application is an acoustic cloak that could, in principle, mask a submarine from sonar. Just as an ocean wave deforms the sea surface as it passes, so too sound waves deform the materials they pass through, squeezing them in some places and stretching them in others. Wegener and his colleagues have created a prototype acoustic cloak that reshapes those deformations. The cloak consists of a sheet of PVC plastic with a specific pattern of holes that are filled with a rubbery polymer. It works by steering sound waves around a central cavity, muffling noise inside it.

Another prototype is an "unfeelability cloak". Ordinarily, if you push down on an elastic material when it sits over a hard object you would feel the object through the material. Wegener's unfeelability cloak is a sculpted mesh of soft plastic that reshapes deformations caused by pressing with your fingers, much as the material in his acoustic cloak reshapes the deformations caused by sound waves. In this way the cloak masks the presence of a lumpy object from our sense of touch. The result is more or less the opposite of the fairy-tale mattress in The Princess and the Pea. (You could probably use mechanical metamaterials to make that, too.)

Huge metamaterial-type structures around the base of a building could even redirect seismic waves to cloak the building from earthquakes. Early tests of this idea suggest that it's feasible. Researchers at the University of Aix Marseilles, in collaboration with a French engineering company, drilled a grid of five-metre deep boreholes in a bed of silty clay near Grenoble, France. They calculated the dimensions of the holes and the grid required to create a geological metamaterial that would reflect the high-frequency seismic waves produced in earthquakes.

Sure enough, when the French researchers shook the ground on one side of the array using mechanical vibrators, the shaking on the other side was reduced considerably — in some places by more than four-fifths — compared to what it would have been without the array. This isn't exactly seismic invisibility, since the array reflects the waves rather than diverting them, but the principles, based on transformation optics, are the same.

A cloaking grid that masked damaging lower-frequency seismic waves from earthquakes could be tougher to construct, though, because the holes would have to be correspondingly bigger. They wouldn't necessarily have to be empty – it might work just to fill them with a softer substance than the surrounding ground.

ALL THIS IS A LONG WAY from Plato's Ring of Gyges. But perhaps we've possessed the trick of invisibility all along. Stage magicians make things vanish all the time with a bit of skilful misdirection. They know that invisibility is not just, or even mainly, an optical phenomenon, but a mental one.

Simply perceiving yourself as invisible has psychological effects. In a recent piece of high-tech deception, neuroscientist Henrik Ehrsson and his team at the Karolinska Institute in Stockholm, Sweden, fitted subjects with a virtual reality headset that made them feel as if they had an invisible body. With the headset, each subject saw a paintbrush that seemed to brush the empty space where his body should have been, while at the same time his real body was touched by a similar paintbrush. This combination of illusory and tactile sensations gave them a strong sense of having an invisible body. So much so, that when they were subjected to an audience of people watching them intently, the subjects reported experiencing far less anxiety about being scrutinised – and their skin's electrical conductivity confirmed this.

STAGE MAGICIANS KNOW THAT INVISIBILITY IS NOT JUST AN OPTICAL PHENOMENON BUT A MENTAL ONE.

Will such a feeling of invisibility (even if it's illusory) erode our moral sensibility, as Plato and H. G. Wells predicted? If so, the matter isn't likely to end well, as Wells' invisible character Griffin discovered. Despite being unseen, he is eventually cornered by a mob of locals who beat him to death – whereupon his lifeless body reappears, "naked and pitiful on the ground".

Will we too succumb to the dangerous allure of invisibility? Perhaps. Just witness the nastiness of anonymous internet trolls. The Karolinska team plans to use their virtual-reality set-up to expose their "invisible" participants to dilemmas and see whether their cloak recalibrates their moral compass. Will they, like Griffin, start to run off the rails? If so, we might wonder whether invisibility is desirable after all.

PHILLIP BALL wrote *Invisibile: the dangerous allure of the unseen*, published by Viking Penguin.

IMAGES
01 Marian Beck
02 Yunseok Oh-Park / GDS Architects
03 Ken Straiton
04 Jason Edwards / Getty Images

STALKING KILLER CATS

Catching repeat offenders could stop feral felines from wiping out endangered species. RICHARD CONNIFF reports.

→

A SINGLE, murderous cat can foil the efforts of conservationists.

01

DOMESTIC CATS have become one of the most dangerous species on Earth. They have driven some 30 bird and mammal species to extinction and threaten dozens more. When conservationists are trying to restore a threatened animal to an old habitat, a single murderous cat can destroy all their efforts.

NOW FRUSTRATED Australian scientists are proposing to apply criminal forensics and even a poison pill to identify and eliminate problem cats – while possibly sparing others that may be innocent. In an article in the journal *Biological Conservation*, researchers call these experimental techniques "predator profiling".

A team of researchers led by ecologist Katherine Moseby at the University of Adelaide examined attempts to restore what are known as "challenging species". The phrase generally describes mammals that are so big, toothy or mean that you might not think the average outdoor cat would pose a threat to them. Many of these species – including the western quoll, the burrowing bettong and the rufous hare-wallaby – are largely unknown outside Australia, and that's the point. They are found nowhere else in the world and are part of Australia's natural heritage. Cats, which were introduced to Australia about 200 years ago, have proved capable of killing native species weighing up to six kilograms.

These cats are a nightmare for restoration biologists. In one case, 13 of 31 rufous hare-wallabies that were being reintroduced into their desert environment quickly vanished and feral cats seemed to be responsible. When researchers trapped and euthanased a single five-kilogram cat the killing stopped.

The same thing happened while a brush-tailed bettong – a small, rare, nocturnal marsupial – was being reintroduced in the wild. One by one, the radio collars of 14 animals – one fifth of the total – gave out the "dead" signal over four months. Eliminating a single 5.7-kilogram cat ended the problem.

Western quolls are a predatory marsupial once common throughout Australia. For their study, Moseby and her colleagues looked at an attempt to reintroduce 41 western quolls into Flinders Ranges National Park in South Australia. They retrieved the 11 animals that died and, among other forensic techniques, took swabs of the saliva on the radio collar and on the carcass, matching them with samples from captured cats. In one typical case a professional shooter killed a large male cat near a quoll kill site. Its DNA was identical to that found on the dead quoll, its teeth matched the bite marks on the victim and it had quoll fur in its stomach.

Moseby says a problem they have encountered when reintroducing challenging species is that certain cats – generally large males – learn to specialise in that prey, coming back again and again. Ducks aren't exactly challenging, but swimming usually is – for cats. Yet in one notorious case, a cat was shot while swimming out to grey teal nests—and it had grey teal in its stomach. The cat was a serial killer.

Moseby likens the proposed response to killer cats to the way society generally deals with other "problem predators". The conventional practice is not to eliminate all tigers or polar bears, say, but to target only those individuals that have become a menace to humans.

In the case of cats, attempting to eradicate the entire free-roaming population isn't generally practical, except on small islands. (Between 15 and 23 million wild cats are believed to live in Australia and its islands. Researchers say the cats kill 75 million native animals each night.)

Moseby says identifying and eliminating the problem felines alone is more efficient than eradicating all cats – although it is still an enormous task. Because DNA and other forensic techniques are relatively expensive another approach may

02

In Australia, cats have been estimated to kill 75 million native animals each night. Unique and rare species, such as this rufous hare-wallaby and joey, are particularly vulnerable to feline predators.

require eliminating the *type* of cats most likely to pose a problem – such as those large males that are prone to hunting challenging prey. That might involve setting large box traps or using auditory signals to target those cats. "We're trying to show that not all cats are created equal," says Moseby. "Only a proportion of the animals are doing the damage."

But aren't some cat owners going to interpret this approach to mean their cat is innocent and should roam free? "I can see that there's a potential for that," she acknowledges. "But we're only talking about challenging species – prey species that are larger, more aggressive and have defensive mechanisms. Whereas for things like native lizards or native mice, they might be vulnerable to any cat."

generations, even with cats in the area.

"We don't want to be building fences forever and excluding these animals completely," she says. That just encourages prey animals to become more naive about predators.

Another more radical initiative in the works at the University of Adelaide would automatically target and kill problem cats at the scene of the crime. To this end researchers are developing "toxic microchips" says Moseby, that could turn a prey animal into "a toxic Trojan horse".

The chip is implanted in an animal's skin and would not harm the carrier. It uses a local toxin to which indigenous species have adapted but introduced species have not. The chip is designed to break open during the shredding and rending

"NOT ALL CATS ARE CREATED EQUAL. ONLY A PROPORTION OF THE ANIMALS ARE DOING THE DAMAGE."

03

Caught in the act: a feral cat hauls off an endangered bridled nail-tail wallaby in Queensland, Australia.

That's why Australia recently launched a "war on cats", with a plan to cull two million feral cats over the next five years. Environment Minister Greg Hunt describes the program as an attempt to "halt and reverse the threats to our magnificent endemic species". (In New Zealand, where cats have also devastated endemic species, there has been a proposal to ban all domestic cats.)

But cats are unlikely to go away anytime soon. So Moseby is working on one initiative to make native species more cat-savvy. The researchers now have 450 burrowing bettongs – small marsupials – in a 14.5-square-kilometre fenced paddock with two cats. Their aim is to fast-track evolution and breed up populations that can survive over a few

of a predator attack and thus poison the killer – specifically a cat or another introduced species.

That may sound like cruel and unusual punishment to cat lovers. But if their cats are as innocent as they like to say, they won't encounter the problem in the first place.

RICHARD CONNIFF is an award winning science writer based in Connecticut, US.

IMAGES
01 GlobalP / Getty Images
02 Roland Seitre / Getty Images
03 Queensland Parks and Wildlife Services

THE WOMAN SCIENCE FORGOT

Émilie du Châtelet was a gifted mathematician and Voltaire's mistress. Together they spearheaded Newton's revolution in France. ROBYN ARIANRHOD tells the tale.

→

A PORTRAIT OF Émilie du Châtelet, attributed to Maurice-Quentin de La Tour.

01

A SPIRITED DEBATE RAGED in 18th century Europe about what was driving the movements of the planets. In England, Sir Isaac Newton and his followers said it was gravity: the same invisible force that propels a falling apple also commands the planets in their marvellously ordered paths.

WHEN ÉMILIE MOVED TO CIREY TO JOIN HER LOVER, TONGUES WAGGED SALACIOUSLY.

ON THE OTHER SIDE of the Channel, many Continentals favoured René Descartes' theory of a swirling cosmic "ether" that, like a celestial tornado, swept up the planets in its wake.

This disagreement is more than an historical curiosity – it went to the heart of what it takes for a proposition to qualify as a truly scientific theory.

An unlikely pair of champions helped win the victory for Newton in Continental Europe: France's best known and most controversial playwright, Voltaire, and his lover, mathematician Émilie du Châtelet. Her scientific work includes what is still the definitive French translation of Newton's *Principia*. Yet after her death she was all but forgotten. If she was remembered at all, her achievements were often belittled, lost in the shadow of the "great men" in her life. But modern-day historians have rediscovered Émilie, and her story is inspiring new generations of women mathematicians, myself included.

BORN IN PARIS in 1706, she is surely the most glamorous female mathematician in history. Tall and aristocratic, passionate in both her intellectual and amorous pursuits, she was larger than life. Too large for most people at the time: too ambitious, too intellectual, too emotional and too sexually liberated. Too much of a feminist, too: she pulled no punches when writing of her struggle to educate herself in higher mathematics and physics (because girls were denied access to good schools, let alone universities): "If I were king," she wrote, "I would reform an abuse which effectively cuts back half of humanity. I would have women participate in all human rights, and above all, those of the mind."

At 26, she captivated Voltaire, who was seduced by her brains as well as her beauty. He was already notorious as an upstart commoner with a wicked wit. Émilie, by contrast, was born to the aristocratic life; her father had been chief of protocol at Louis XIV's court at Versailles. She'd been married off at 18 to the Marquis du Châtelet, with whom she soon had three children. Having done their duty for the Châtelet line, she and her husband then lived relatively separate lives – a common situation in aristocratic families. Less common was the remarkable friendship that developed between husband and wife, so that ultimately the marquis supported not only Émilie's unusual ambition, but also her passionate relationship with Voltaire. Taking a lover was the norm at that time of arranged marriages, but Émilie and Voltaire scandalised polite society when they set up house together: extra-marital love affairs were supposed to be discreet dalliances, not alternative marriages. Curiously, their domestic arrangement – and their role as Newtonian revolutionaries – were as interconnected as the mysteries of the cosmos they set out to explain.

VOLTAIRE'S ATTRACTION TO NEWTON sprang from the playwright's exasperation with France's conservatives and elites – something he made clear in his satirical writing. By the time he met Émilie in 1733, his propensity for upsetting powerful people had already landed him in the Bastille for 11 months – and in the late 1720s he had been forced into exile for a couple of years. A fortunate exile, as it turned out, because he'd gone to England, where he met some of Newton's leading disciples – Newton himself was well into his 80s by then.

London had been abuzz with Newton, and when the great man died in 1727, Voltaire attended his funeral in Westminster Abbey. Such official veneration of a scientist was unknown in Voltaire's France, and it impressed him no end. So much so

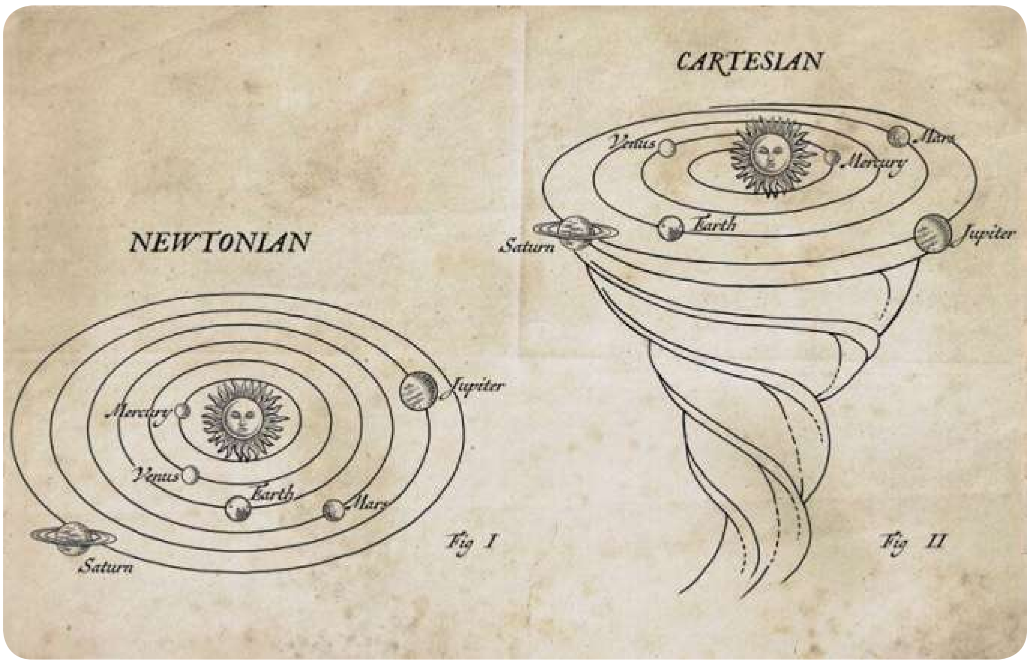
that he wrote a series of essays about the English: their constitutional monarchy, relative religious tolerance, rational Newtonian science, and new breed of empiricist philosophers, notably Newton's friend and disciple John Locke.

Voltaire published these essays in England. In early 1734 he told a friend he was holding off publishing the longer French version – *Lettres Philosophiques* – for fear of the clergy of the French court. The French edition included an unfavourable critique of French mathematician Blaise Pascal's religious writings, and a defence of Locke's assertion that thought might arise via a material mechanism – an idea that had led nervous theologians on both sides of the Channel to assume Locke was saying there was no such thing as an immortal soul.

today we regard Descartes's theory as pseudo-scientific, with its swirling vortices of invisible ether dragging the planets in their orbits. No one knew what this ether was made of, or why it swirled like a tornado. Voltaire pointed out the hypocrisy of believing in magical ethereal whirlpools while rejecting gravitational attraction. His essay shows that for many 17th century theorists, the rules of what constitutes a truly scientific theory had not yet gelled.

Mathematics was crucial to Newton's approach. Not that Voltaire was on top of the mathematical subtleties that showed just how superior Newton's theory was – he would need Émilie's help for that. But such help would have to wait because in April 1734, Voltaire's French publisher released *Lettres* in France without his permission. An arrest warrant was issued and Voltaire went into hiding. Émilie raged to her friends that France's treatment of its greatest writer was unjust. Her appeals to the authorities, as well as those of her husband and other aristocratic friends, bore fruit. Voltaire was allowed to return to France, where he lived under a kind of house arrest at the Châtelets' run-down château at Cirey, in Champagne.

02



Newton's proposal that gravity held the planets in place was based on observations and mathematics. Descartes' theory of a swirling cosmic ether was an imaginative conjecture.

To tangle with religious dogma was dangerous. But Voltaire's support of Locke's and Newton's ideas also challenged French national pride. One of his essays criticised the "Cartesians" who dominated Paris's Academy of Sciences. These men – followers of 17th century philosopher René Descartes – had great difficulty with Newton's theory of planetary motion. How could the Sun's gravity reach across millions of kilometres of empty space to influence the planets? They thought it smacked of pseudo-science – like astrology or alchemy. This is ironical, in hindsight, because

When Émilie moved to Cirey to join her lover, tongues wagged salaciously, even hatefully, because she had dared to flout the rules of propriety. She and Voltaire set about turning Cirey into an informal

03

Portrait of Voltaire, the controversial Enlightenment playwright, who took up Newton’s cause after living in London during his exile from France.

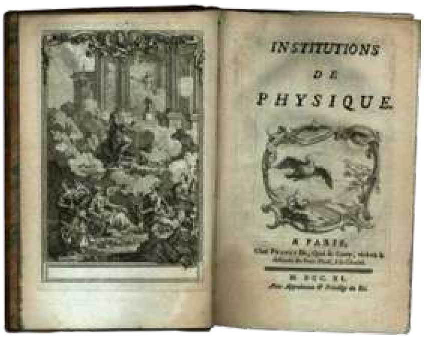
academy where they studied, wrote, discussed philosophy and hosted free-thinking intellectuals. It was an idyllic arrangement, although sometimes Voltaire felt he wasn't working hard enough on his poetry and plays. "Too often," he said, "the supper, Newton and Émilie carry me away". He was referring to their preparations for a serious popularisation of Newton's ideas, to be called *Elements of Newton's Philosophy*.

Émilie would take this project even further in a 180-page "commentary" she appended to her translation of Newton's *Principia*. This included a relatively accessible reader's guide to the main arguments in Newton's gravitational theory of planetary motion. It also described applications of Newton's theory by her eminent mathematical friends and sometime tutors, Alexis Clairaut and the dashing Pierre-Louis Moreau de Maupertuis, as well as an update on Newton's gravitational theory of the tides by their colleague, Swiss mathematician Daniel Bernoulli. Émilie's appendix also included her own reworking of some of the *Principia*'s key proofs in the language of calculus. Newton (and independently German mathematician-philosopher Gottfried Leibniz) had invented calculus – the maths that describes and predicts how things change, such as the position of a falling apple or a planet in the sky. But apparently Newton felt calculus was too new to convince people of the validity of his radical gravitational theory. Instead he established most of his arguments with ingenious but idiosyncratic geometrical proofs – the kind of logical, rigorous approach perfected by the ancient Greeks. Émilie re-wrote some of these proofs using the cutting-edge dy/dx calculus notation that had been developed by Leibniz.

ÉMILIE'S FAME AMONG European intellectuals came not from her translation of the *Principia* but from an earlier work of popular science – called *Institutions de Physique* (*Fundamentals of Physics*) – in which she bravely attempted to integrate the work of Newton and Leibniz. Scientific opinion at that time tended to favour either the Englishman or the German. It was not only about nationalism, it was also a debate about what constitutes a theory of nature. Newton focused on providing testable explanations for what we can observe in the Universe, while Leibniz emphasised philosophical questions about the nature of existence. Émilie's brilliance lay in her ability to understand the subtleties of both Newton's theory and Leibniz's philosophy.

Voltaire, on the other hand, was entranced with Newton and didn't bother much with Leibniz – he and Émilie remained in feisty disagreement on the matter. In his novella, *Candide*, he would lampoon Leibniz's "best possible world" philosophy – Leibniz's attempt to reconcile God's goodness with the suffering and evil in the world.

04



Emilie du Chatelet integrated the work of Newton and Leibniz in her book, *Fundamentals of Physics*.

ÉMILIE'S BRILLIANCE LAY IN HER ABILITY TO UNDERSTAND THE SUBTLETIES OF BOTH NEWTON'S AND LEIBNIZ'S PHILOSOPHY.

By the mid-1740s, however, it was Emilie's work on the *Principia* that was closest to her heart – although translating 500 pages of Latin and intricate geometry, and checking and re-checking her calculus proofs, was arduous. "I have never made such a sacrifice for reason as I have by staying here and finishing this book. It is an awful job, for which one needs a head and a constitution of iron," she lamented. Nevertheless, both she and Voltaire had been seduced by Newton's logic. In showing how profoundly the human mind can penetrate the mysteries of nature, Newton gave his disciples hope that reason would triumph over superstition, ushering in a rational, secular approach not only to "natural philosophy", but also to politics and ethics.

IN PARTICULAR, Émilie and Voltaire realised that Newton had created the blueprint for modern theoretical physics. He did this by keeping religion and philosophy separate from what we can actually observe, and from what we can infer from those observations. The Cartesians, on the other hand, belonged to the past – an era when scientific theorists were primarily philosophers. The natural philosopher's job was not so much to measure and quantify as to be metaphysical – to look "beyond" physical observations to the ultimate cause or nature of a phenomenon. Take the ether whirlpool hypothesis: it was an attempt to imagine what might be causing the planets to move through the sky, and it was consistent with the "self-evident" notion that

WHAT MAKES A GREAT THEORY TODAY?

TECHNOLOGY HAS OPENED the window to a Universe that seems even more mysterious than it did three centuries ago. We are dazzled by dark energy, dark matter, and quantum-generated multiverses consisting not only of our own "best possible world" – but every possible world. What happened to Newton's method: proceed from a set of physical principles and mathematical laws to a beautiful theory? Some of these new ideas seem to take us back to Descartes's ether.

But Newton would probably have had no trouble with our weird modern theories. Like his theory of gravity, modern theories make bold leaps that the Cartesians would never have accepted. We still don't really know what gravity *is*, so what would the Cartesians have made of such counter-intuitive ideas as mass-energy equivalence, or curved space-time or antimatter? Although these ideas are weird, they have arisen from theories based, like Newton's, on experiment and mathematics – in contrast to the ether.

A great theory does not have to be – indeed *cannot* be – a perfect fit to the physical world. Newton's gravitational theory was long ago subsumed into Einstein's general theory of relativity, which itself will no doubt need updating as we learn more about the Universe. Yet both theories successfully predicted new and unexpected physics, and they remain incredibly accurate: Newton's theory fits observed planetary motion to better than 0.0001%, while Einstein's theory has passed all experimental tests so far. This is why they will always be what Roger Penrose called, in *The Emperor's New Mind*, "superb" theories. (Others in this category include Maxwell's theory of electromagnetism, quantum electrodynamics, and quantum mechanics.)

During the process of finding new theories, or adapting old ones so they are a better fit with more accurate data, all sorts of wild conjectures emerge and heated debates take place. Using Penrose's terminology, these emerging theories can be categorised as "useful"– such as the Big Bang standard model – or "tentative" – such as the cyclic model of the Universe, or string theory that unites gravity with the other fundamental forces. A theory will become "superb" only when it has made predictions that are experimentally confirmed at a high level of accuracy and with a wide range of applications or explanations.

↑ Forget the apple: it was maths that led Newton to his theory of gravity.

CREDIT: PHOTOS.COM / GETTY IMAGES

forces must make direct contact with objects if they are to move them. But there was no evidence for this ethereal substance. Nor did the ether theory predict anything about the actual movements of the planets. In fact, Newton showed a mathematical vortex was incompatible with German astronomer Johannes Kepler's planetary observations.

Newton, on the other hand, began with Kepler's analyses. (Kepler in turn had spent years sifting through Danish astronomer Tycho Brahe's observations of the planets' positions in the sky at different times of the year.) Kepler was able to fit a mathematical curve to each planet's orbit and he realised they form ellipses around the Sun. He also found relationships between the size of an orbit and the time it took for the planet to orbit the Sun. Kepler's laws provided an accurate mathematical description of these orbits.

But Newton's goal was to develop a theory about why the planets moved at all.

Newton used Kepler's analysis to show that the force needed to move a planet on an elliptical path around the Sun must obey an "inverse-square law". That is, as the distance from the Sun increases, the force becomes weaker; for instance, if the distance increases two-fold, the force is only a quarter of what it was before – the inverse of two squared. So planets further from the Sun experience less force and have wider, slower orbits. Newton also showed that moons with circular orbits, and comets whose orbits were elliptical, parabolic or hyperbolic, were also governed by this law.

But Newton's genius did not stop there: he realised this celestial inverse square force was the same force that makes apples fall on Earth. In other words, planets and moons were falling around their parent body. Galileo had explored the nature of the acceleration due to gravity by rolling metal balls down a plank, publishing his results in 1638, 49 years before the publication of the *Principia*. To show that this same gravitational force was acting on the Moon, Newton calculated the Moon's circular acceleration (based on its speed and distance from Earth) and found that it was about 1/3,600th of the acceleration of a falling body here on Earth. The Moon is about 60 times further from the centre of the Earth than we are on its surface, so the inverse-square law fitted!

Of course, Newton's chain of reasoning was much more complex than this. What is important, from a modern perspective, is that his theory could be used to make testable predictions. Newton lived to witness one of its earliest confirmations – the total solar eclipse of 1715 that caused darkness to fall across England, northern Europe and northern Asia. It was a thrilling public occasion, but an even more spectacular confirmation came 32 years after his death: the return of Halley's comet in 1759.

In the 1730s and 40s Émilie and Voltaire helped to articulate and popularise Newton's extraordinary achievement – a paradigm shift in our understanding of the Universe. In *Elements of Newton's Philosophy*, Voltaire said the Cartesian emphasis on metaphysical causes was "the surest way of losing our way. Instead, [like Newton] let us follow step by step what actually happens in nature: like voyagers who have arrived at the mouth of a river, we must travel up the river before imagining where its source is located."

Not even Newton's great contemporaries Leibniz and Christiaan Huygens had understood Newton's paradigm: they agreed the theory of gravity was a mathematical *tour de force* that accorded remarkably well with the physical evidence of planetary motion. But they were not convinced gravity could act across the vastness of the Universe. Since Newton had given no idea of how this might happen, they rejected his theory as a return to mysticism.

Newton had, in fact, tried unsuccessfully to find a mechanism by which gravity acted, but he refused to include untested speculations in his rigorous *Principia*. He left such a discovery to posterity (to Einstein, so far), saying: "It is enough that gravity really exists and acts according to the laws we have set forth, and is sufficient to explain all the motions of the heavenly bodies and of our sea [the tides]." Enough indeed: today we know that for most applications within the Solar System, Newton's theory is accurate to one part in ten million.

ÉMILIE AND VOLTAIRE HELPED TO ARTICULATE AND POPULARISE NEWTON'S THEORIES.

BUT NOT EVEN NEWTON got everything right – especially when it came to the nature of light and heat. Back in 1738, this was such an open question that the Paris Academy of Sciences made it the topic of its annual essay competition, which Voltaire planned to enter. He and Émilie had an impressive laboratory with a large reflecting telescope, high-quality prisms, lenses and accurate measuring scales. They were fascinated by Newton's optical experiments – including those that proved white light is made up of the spectrum of colours. But Newton did not have a theory about the fundamental composition of light, although he suggested it was made of tiny particles.

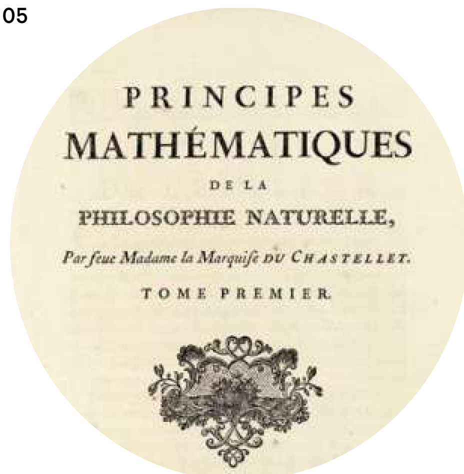
Voltaire assumed that heat, too, was made of particles. With Émilie's help he heated huge amounts of metal in the forge at Cirey, weighing

the metal before and after heating to see if he could detect an increase in mass – the mass of the additional heat particles. After months he had no consistent results, and Émilie began to believe heat had no weight. Voltaire was so passionately Newtonian that he wouldn't listen to her arguments – which included the possibility that the extraneous charcoal coating the burned metal would weigh more than the heat, so that the experiment could never work.

Émilie also believed, contrary to Newton, that light had no weight. Her conclusion was based on an ingenious thought experiment. She calculated that even if a light particle weighed less than a trillionth as much as a cannon ball it would feel like a cannon ball when it hit our eyes because it travelled so fast!

ÉMILIE HAD HOPED HER WORK ON NEWTON WOULD LIVE FOREVER.

05



Émilie's commentary and translation of Newton's *Principia* was published a decade after her death.

She had other innovative ideas about light and heat, too – for instance, that the different colours of light would have different amounts of energy and different temperatures, a conjecture that would be confirmed half a century later. Émilie did not chase up her ideas on light and heat with experiments. But she expressed them in a solo entry for the Paris Academy's essay competition. It was submitted anonymously and in secret. She didn't want to hurt Voltaire's feelings by publicly disagreeing with him – and didn't want to expose herself to ridicule, as a woman daring to enter male territory. The only person she trusted with her secret was her husband! (He joined the Cirey household during rare respites from his military service – and his mistresses.)

As it turned out, Voltaire was proud of Émilie's essay, and thought she should have won the competition. And she thought he should have done: she complained to a friend that the Academicians were too Cartesian to be impartial. But not so partial that they didn't agree that each of the papers from Cirey was sufficiently interesting for publication, along with the winners, in the Academy's proceedings. And so Émilie became the first woman to have a scientific paper published in this prestigious journal.

THERE IS NO HAPPY ENDING to this story. In 1749 – having penetrated the scientific establishment in a way few women had ever done – Émilie died as only a woman can die, after giving birth (to the child of her new lover, the Marquis de Saint Lambert). She was 42. Society gossips believed she'd got what she deserved for living so outrageously, so freely. Voltaire stayed with her until the end. Although they were no longer lovers, he'd remained "a tiny planet in her vortex, hobbling along in her orbit", as he wrote in a letter to a friend.

Émilie had hoped her work on Newton would live forever. But soon after her death, her scientific reputation faded, too. Voltaire lost interest in science, and her *Principia* languished in a drawer – until Clairaut ushered it into print. He'd checked her calculus proofs in the months before she died, and he'd refined Newton and Halley's calculations to obtain the accurate prediction of the return of Halley's comet in 1759. What better celebration than to publish Émilie's book in the same year! She would have been delighted: she'd known the comet held a key to securing Newton's reputation.

And I am delighted to be able to celebrate her achievements here, and to honour the sacrifice she made "for reason". She was an inspiration to me in my own journey into higher mathematics, and she is continuing to inspire women – and men – because of her mathematical achievements against such odds, and her courage in living life to the full.

ROBYN ARIANRHOD is the author of *Seduced by Logic: Émilie du Châtelet, Mary Somerville and the Newtonian Revolution* (UQP, OUP).

IMAGES

01 DeAgostini / Getty Images
02 Bob Venables / Illustration Ltd
03 Leemage/Corbis
04 ViaLibri
05 Camille Souget Librairie

PEOPLE, CULTURE
& FICTION

SPECTRUM

ZEITGEIST

A science nerd goes viral

ANDREW MASTERSON speaks to Derek Muller about his YouTube science channel Veritasium →

01

ZEITGEIST

A science nerd goes viral

→ Look at the agenda for any major science communication event – December's World Congress of Science and Factual Producers in Vienna, say, or next year's World Science Festival in Brisbane – and you'll notice at least one session dedicated to social media.

In recent times, the use of online platforms as vehicles for science news and gossip has exploded, exemplified by the extraordinary popularity of British blogger Elise Andrews' Facebook site, I F*cking Love Science, which boasts more than 20 million "likes".

Ms Andrews' popularity and genius lies in her skill in agglomerating and curating third-party content. Another rising star of social media science, physicist Derek Muller, 37, has taken a different route. The Canadian-Australian dual citizen is the presenter of his own YouTube channel, Veritasium.

Comprising a rich miscellany of enthusiastic, humorous reportage and demonstration, Veritasium, as of writing, enjoys 2.4 million subscribers – a circulation that all science magazine journalists, and most science television producers, can only dream about.

VERITASIUM WAS THE PRODUCT OF YOUTHFUL AMBITIONS TO BE, VARIOUSLY, AN ACTOR, A FILMMAKER AND A PHYSICIST.

Sometimes, though, dreams and reality collide. This year, Muller's career has enjoyed a further boost and a big injection of mainstream credibility. He was plucked by Emmy Award-winning Australian science television-makers Genepool Productions to front a multi-part documentary. In various iterations, *Uranium – twisting the dragon's tail* will screen in Australia, Europe and the United States.

Speaking from his home in Los Angeles, Muller explains that Veritasium was the product of youthful ambitions to be, variously, an actor, a filmmaker and a physicist. A PhD in science communication from the University of Sydney helped to consolidate his ambition.

"That led to a merging of all my major interests: the craft of filmmaking, the content of science and engineering, and teaching people," he says.

For want of any other outlet, he began making science-themed YouTube clips and set up the Veritasium channel. Within a few months his work was noticed by the producers of ABC-TV's long-running science program *Catalyst*, and he was offered some gigs as a guest presenter. While he was learning the television ropes at Aunty, however, something strange was happening back on the Net. His little low-budget videos were going gangbusters.

"When I started I never had any real ideas that it would get big", he says. "When I started I was getting barely 50 views for each video. I was sending them around to family and friends – saying, 'please watch what I'm doing!'

"I remember thinking to myself that if I want to get a million views, then I should maybe make a thousand videos in a year, and then if each one got 10,000 views … I was doing that sort of math and it sounded like a lot. It felt like it was impossible. Every step of this for me has been completely unexpected."

02

Mueller's YouTube science videos range from how chameleon's change colour to how special relativity makes magnets work.

Such is the arithmetical nature of social sharing, that when a video is passed on frequently the number of viewers it attracts can expand exponentially. For Muller, this came as a welcome and timely surprise.

"I was never going to be a full-time host on *Catalyst*", he says. "So I had to find something else to do with my time, and for me that was continuing to build YouTube. Eventually, YouTube got to the stage where it was *bigger* than *Catalyst*. It had more reach, it was more global and I had complete creative control."

That last point – about complete control – is perhaps the main area in which traditional science media (such as this magazine – or *Catalyst*, for that matter) and social science media differ. For journalists in mainstream media,

03

Muller at Fukushima wearing a protective mask and holding a geiger counter. He visited the site of Japan's worst nuclear accident during filming of the documentary series, *Uranium*.

work is always subject to more or less stringent review by editors, sub-editors and directors. Far from being restrictive, pre-publication questions serve as a valuable error-detection mechanism.

In Veritasium, such checks and balances are absent. Derek Muller's journalism has no safety net.

"It's scary! Of course it's scary," he says. "I have gotten things wrong before. There was one video in which I talked about how nothing could go faster than light. There was one matter I mentioned, and after it came I out I got an email from a general relativity professor saying: 'Derek, that's not quite true.'

"Because of that email, I made another video, called 'Misconceptions about the Universe'. When mistakes happen, I do my darnedest to correct them. And, of course, I will often consult with experts before I make a video."

A subscriber base of a couple of million, a telegenic presence and a firm grasp of physics is a potent combination. Certainly it was enough for Genepool Production's creative director Sonya Pemberton to offer Muller the presenter role in her company's ambitious three-hour documentary about uranium and the rise of nuclear power.

It was a role he readily accepted. It took him through nine countries – but also made him subject to a much more hierarchical directorial process than the one used for Veritasium.

"I didn't have to focus my own camera or deal with my own audio. All the locations, everything was organised. That meant I was able to focus just on the performance aspect. It was invaluable to have a director there to evaluate my performance and say, 'no, we're going to tweak this' or 'no, you're too presentery'. For me, that was a lot of fun, another part of the creative process."

So will this be, ultimately, a tale of the prodigal presenter: the man who wandered off into YouTube-land but later returned to the 'proper' world of science television?

"I love the idea of having a presence in both worlds," he says. "What I can do on Veritasium strengthens the documentary. I did a Veritasium film about radioactivity while we were making *Uranium*: it's got over two-and-a-half million views. All those viewers will be cued to watch the documentary – and the documentary viewers will be drawn into the online world."

He smiles. You can see why.

ANDREW MASTERSON is an Australian science and culture writer. He is also a prize-winning crime novelist.

IMAGES
01 Young & Percival / Genepool Productions Pty Ltd
02 YouTube / Veritasium
03 Josephine Wright / Genepool Productions Pty Ltd

SNAPSHOT

The tree inside a silk moth

TAKE A DEEP BREATH: this is not some sea monster dredged up from the midnight zone. It's a part of a silk moth caterpillar's airway, as seen through a microscope.

All insects, including caterpillars, do not have lungs. Instead, a tree-like network of tubes called trachea permeate their body. Air diffuses through the trachea to supply the insect's cells with oxygen.

This image, of a dissected section of the silk moth caterpillar's tracheal tree, was captured by biologist turned nature photographer David Maitland. The image forms part of the UK Royal Photographic Society's 2015 International Images for Science exhibition.

IMAGE
Dr David Maitland FRPS

ISSF 2015
FRONTIERS IN SCIENCE

International Student Science Fair

A science conference for the scientists of the future

7th to 11th Dec, 2015, at John Monash Science School, Melbourne

www.issf2015.org

- 5 days
- 15+ countries
- Over 500 talented high school science students
- 100 inspired science teachers and school leaders

- Industry site visits
- Monash University workshops
- CSIRO Lab tours
- Victorian Specialist Science Centres
- Research presentation at the Australian Synchrotron

Supported by leading Australian scientists, educators and community leaders, including Prof Ian Chubb, Dr Elizabeth Blackburn, Prof Alan Finkel, and Anna Burke MP.

Join us for our showcase event as students present their original research projects.

Tuesday, 8th December, 2015
3:30pm to 6pm
Australian Synchrotron
800 Blackburn Road, Clayton, Victoria

JOHN MONASH
SCIENCE SCHOOL

John Monash Science School (JMSS) is Victoria's first specialist secondary school in the Sciences, Mathematics and Associated Technologies. It is a state government co-educational senior secondary school, created through a unique partnership between the Victorian Department of Education and Training (DET) and Monash University.

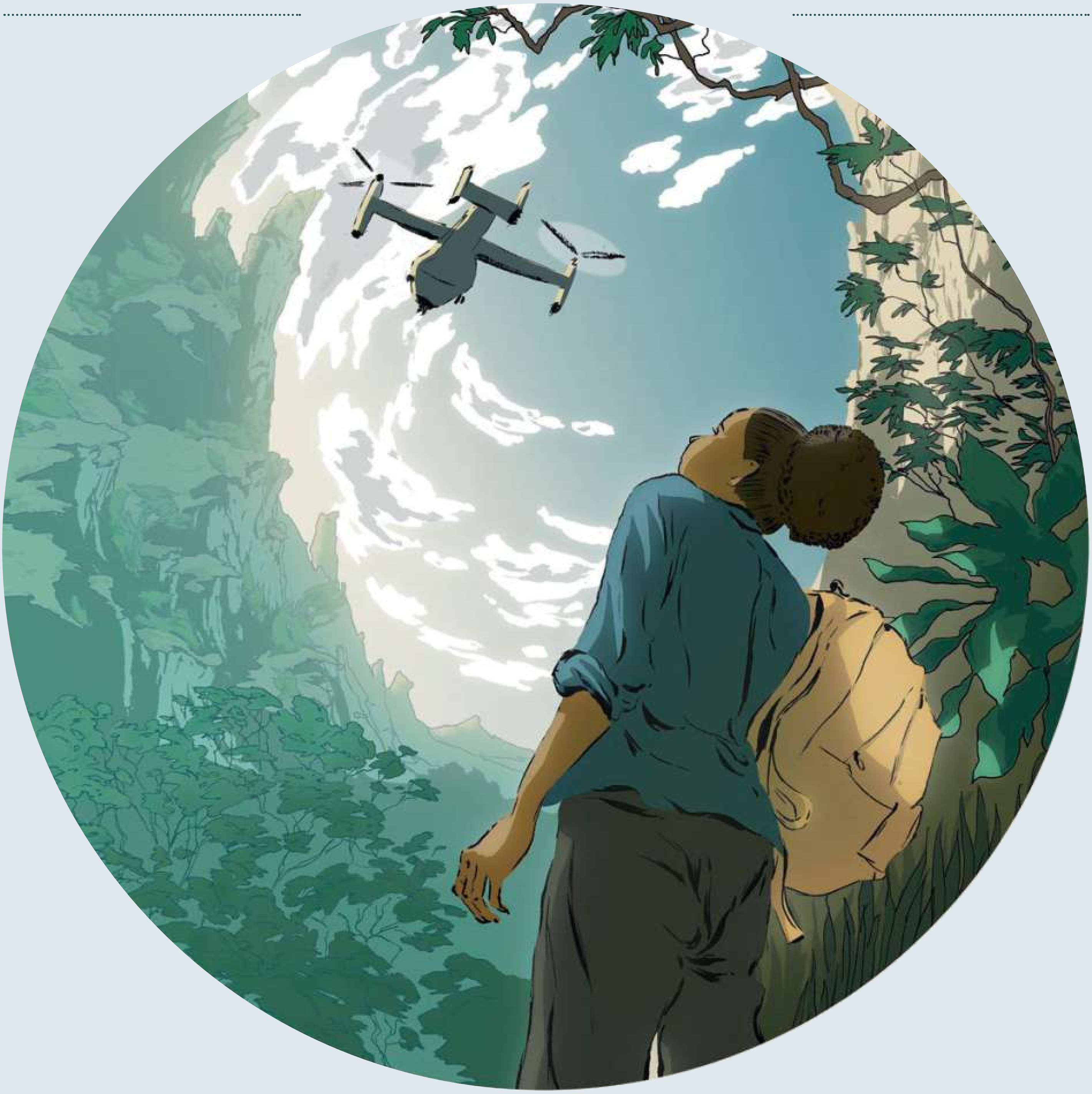
In Year 10 students cover core science in physics, chemistry and biology, as well as choosing an emerging science elective in fields such as astrophysics, nanotechnology, bioinformatics, analytical and spectroscopic science, and pharmaceutical science.

If you have a passion for the sciences, love a challenge and welcome every opportunity to learn, then this is the school for you.

www.jmss.vic.edu.au

SCIENCE FICTION

CATERWAUL



WORDS — EDLYN TOKLEY & SIMON BROWN
ILLUSTRATION — GATSBY

"So what did happen in Willoughby? Was it the plague?"
"No."
"Then what was it?"
"That's not so easy to explain."
"OK. Let's try this from a different angle. Why did everyone start off thinking it was the plague?"
"Because of the all the dead people and all the dead rats."
— Transcript from interview with Dr Sarah Amedi on WorldNetNews, 14 March

THE PROTEIN MICROSPAN implanted in Sarah Amedi's sphenoid bone twinged, pulling a cheek muscle. She turned her head away from the bright sunlight streaming through the tiltrotor's cockpit to read the text that a second later flashed inside her retina.

"Don't get no cold. <3"

The tag was so unlike Cam MacInnes she worried he meant it ironically, then ticked herself off for reading too much into it.

She blinked rapidly three times, bringing up the keyboard under the message, and used her iris to highlight a reply.

"Try not to", she sent. She waited 10 seconds then, almost against her better judgment, sent "<3U2". Then felt like a dill.

The aircraft was losing altitude. Sarah tried to see ahead, but from the back seat her view was distorted by the Plexiglas bubble. All she could make out was the lack of buildings and the grey ribbon of a highway running north to south in the distance.

"We're here," the pilot said in her headphones.

The aircraft slowed to a hover. People were waiting on the edge of a field 30 metres below, holding on to their hats to stop the downdraft blowing them away. Sarah didn't recognise anyone, and her stomach squeezed with nervous apprehension.

They landed with a soft bump. Some of the people rushed forward, crouching, and started unloading the boxes that took up most of the room in the cockpit, ignoring her. When they were gone, the pilot told Sarah to watch out for the wing blades as she disembarked.

"You're not stopping?"

"Another run to do before night."

She took off the headphones, clambered out and hugged her backpack to her stomach as she beetled to the edge of the pad. When the tiltrotor rose into the sky she waved goodbye. The pilot ignored her, and no one else had bothered waving. The downdraft made her hair and the back of her jacket billow. The noise was deafening.

"Sarah Amedi?" someone behind her shouted.

She turned and saw a short, middle-aged woman with greying hair and a tired face. "Yes," she shouted back. "Who are you?"

The woman waited until the tiltrotor had flown away and she could talk normally. "My name is Zuzanna Arad. I'm with Michel Lilar. He asked me to meet you and take you to our lab."

"Oh, thank you."

Arad pointed to her backpack. "That's it?"

"A change of clothing and a toothbrush. I was told it would only be a couple of days."

"That was yesterday," Arad said, leading off.

Sarah followed. "Yesterday?"

"Today I can tell you it will be more than a couple of days."

"There have been developments?"

They reached a blue 4WD and Arad opened the front passenger door for her. "You could say that. We now have seven dead."

Arad got in the driver's seat and they headed north, over a field. After a few minutes they reached a dirt road

that took them to the outskirts of Willoughby, a small town folded into the landscape.

"Dr MacInnes speaks highly of you," Arad said.

"That's good of him."

"We would have preferred him, to be honest, but he'll have his work cut out for him at the university."

Sarah wasn't sure how to react to this, so said nothing.

The dirt road gave way to a sealed one. Houses became more common. No one was on the streets. She kept looking for dead animals, particularly rats. All she saw were cats prowling around gardens; she counted seven or eight.

"Has it spread?" she asked.

"Not in the last two days, as far as we can tell, but we've been warning people to stay indoors. The roads in and out were blocked this morning."

"To stop anyone coming into town."

"And to stop anyone leaving. The detention centre was always secure, of course. This is what passes for the town centre."

They drove by a handful of shops and a modern supermarket, then turned on to a side street that climbed a hill. A base hospital sat at the summit. Built sometime in the 1950s, it was a monument to redbrick architecture.

Arad pulled up behind a more modern and whitewashed ancillary building at the back of the hospital, and led the way through double doors along a corridor with a linoleum floor. The walls were painted green to shoulder height, then white above.

SARAH TRIED TO SEE AHEAD, BUT FROM HER BACK SEAT ANYTHING SHE COULD SEE WAS DISTORTED BY THE PLEXIGLAS BUBBLE.

They went through another set of double doors and everything changed. The hallway was blocked by a long desk, behind which sat a neat looking man in a lab coat with a palmtop in front of him. A policeman who somehow managed to look serious and bored at the same time stood next to him. Behind them was a temporary airlock made from clear plastic sheets and zip-flaps attached directly to the wall. More clear plastic sheeting covered the floor and walls and all the windows without obstructing the light. Heavy black sheets covered three vents in the roof. Sarah could hear the bass chug of a heavy-duty air recycler somewhere in the wing.

"Paul, this is Sarah Amedi," Arad said to the man in the lab coat. He smiled at Sarah then checked his palmtop. He glanced a couple of times between the screen and Sarah's face. "So it is," he said, and handed Sarah an ID tag with a clip. She put it on and the policeman moved aside to let the two women pass.

After going through the airlock, Arad opened the first door on the left. There was a hiss of cold air before she led the way through to a long narrow space. Sarah thought it must have been a ward room before the emergency. A long work desk with computers connected to microscopes was set against the far wall. On either side of the table were specimen cabinets with cool blue neons under the glass sliders. At the end of the room was a mobile morgue unit; it had 12 cabinets – seven had labels.

The lone person in the room was staring at a computer screen.

"Michel?" Arad said.

"It's not the plague," the man said without looking up.

Arad took a deep breath and let it out slowly. Sarah felt as if she'd appeared halfway through a conversation.

MORE CLEAR PLASTIC SHEETING COVERED THE FLOOR AND HALFWAY UP THE WALLS AND ALL THE WINDOWS WITHOUT OBSTRUCTING THE LIGHT.

"You're sure?"

Professor Michel Lilar shrugged. He was a large overweight man in his 70s who looked as tired as Arad. "No sign of buboes or gangrene on any of the victims, nor any trace of *Yersinia pestis*." He jabbed a finger at one of the specimen cabinets. "And the bacillus wasn't found in any of the rats I tested. It is not the plague."

"That's a relief," Arad said.

"That's terrible," Lilar told her. "We know what to do if it is the plague. We do not know what to do if we do not know what is killing everyone." He looked up at her then and saw Sarah for the first time.

"Michel, this is ... "

"Dr Sarah Amedi. Cam says good things about your microscopy work."

"Genetic epidemiology is what I'm best at," Sarah said.

Lilar smiled. "He said you were very direct."

Sarah did not smile. "Did he say anything else?"

He pointed to the mobile morgue and the specimen cabinets. "Rats in the cabinets. In the morgue, two old women, one old man, two children, one young woman eight months pregnant and, as of yesterday, the local football team's best scrumhalf. Take what you need."

"Did it take you long to find out the real cause for the fatalities?"

"There were complications."

"What complications?"

"Political complications."

— Transcript from interview with Dr Sarah Amedi on WorldNetNews, 14 March

SARAH WAS SITTING IN FRONT of a small television in the hospital's staff kitchen that was so old she couldn't change channels with the chip in her head. She found a remote next to the television with batteries taped in place. The kitchen was filled with kettles and electric stove tops, an ancient fridge that sounded like a wheezing water buffalo and two Formica-covered tables that first saw light of day around the time Sarah's grandmother was born. She made herself a hot drink with what she thought might once have been instant coffee, regretting it after the first sip, but there was nothing else on offer.

The news was on. Tom Prince, a local politician, filled the screen. He was being interviewed outside his electoral office. He was dressed in a dark charcoal suit and sweated too much.

"The detention centre should not be here. These illegal immigrants bring diseases into the country. They should be locked offshore like in the old days, at Manus Island and Nauru."

"Nauru's underwater, Mr Prince," one of the journalists pointed out. "That's where some of the refugees are from."

"Pacific islanders should stay on Pacific islands," Prince continued, ignoring him. "It's not our fault their homes have disappeared beneath the sea."

"There's no evidence the outbreak originated in the detention centre," a second journalist said.

"The first victims to die came from the detention centre. And the next death came from one of the cleaning staff working at the hospital. Of course that's where the disease came from. You don't have to be a scientist or a doctor to figure that out."

"NAURU'S UNDERWATER," ONE OF THE JOURNALISTS POINTED OUT. "THAT'S WHERE SOME OF THE REFUGEES ARE FROM."

"Yes you do, actually," Arad said as she entered the kitchen, talking over the interview. She opened the fridge and scanned its shelves. "The couple from the detention centre were the first to die, not the first infected."

"How do you know?" Sarah asked, and turned off the television. Her grandparents had fled Biafra 80 years before and made their home in Melbourne: Tom Prince was making her skin crawl.

"Signs and symptoms," Arad answered. She retrieved a small square of cheese and a lettuce leaf and joined Sara at the table. "The first case was an old woman from Willoughby itself, name of Ava Gable." She nodded in the general direction of the converted lab room. "She's corpse number three. At first no one had any idea what she had was serious – her GP thought it was a bad cold – but what's interesting is that this woman was a member of a small group of local citizens who made regular visits to the detention centre to bring the refugees books and DVDs, and toys and pets for their kids."

"Refugees," Sarah said.

"What?"

"You said 'refugees', not 'illegal immigrants'. I like that."

Arad regarded Sarah for a long moment. "Your parents were refugees?" Sarah nodded. "It was my great-grandparents who came here. From Poland, before WW II. They decided to be immigrants before it was necessary to be refugees."

"Did they bring any diseases with them?"

Arad shook her head. "Yours?"

"Nope."

"*TOXOPLASMA GONDII*," SARAH SAID.

Lilar and Arad exchanged glances.

"How many bodies?" Lilar began.

"*All* of them," Sarah interrupted. "Rats as well as people."

"What?"

"All the bodies, human and rodent, are infected."

"But the fatality rate for *Toxoplasma gondii* is negligible in healthy adults."

"I know. We need to find out if the victims were suffering from any other disease or infection, like AIDS. We also need blood tests for the entire population of this town and the refugee centre."

"But that's *hundreds* of people," Lilar said.

"Thanks to Sarah, we have a possible cause," Arad pointed out. "It's our first real lead. And those hundreds of people are already confined and isolated, so that will make the job easier."

Lilar shrugged. "I'll get in touch with our lords and masters. I don't think they're going to like this."

"They'll like it a lot less if people keep on dying," Sarah said. "And while you're talking to them, just in case I'm right, we're going to need a giant bucket of medications to treat the infected. I'll get you a list."

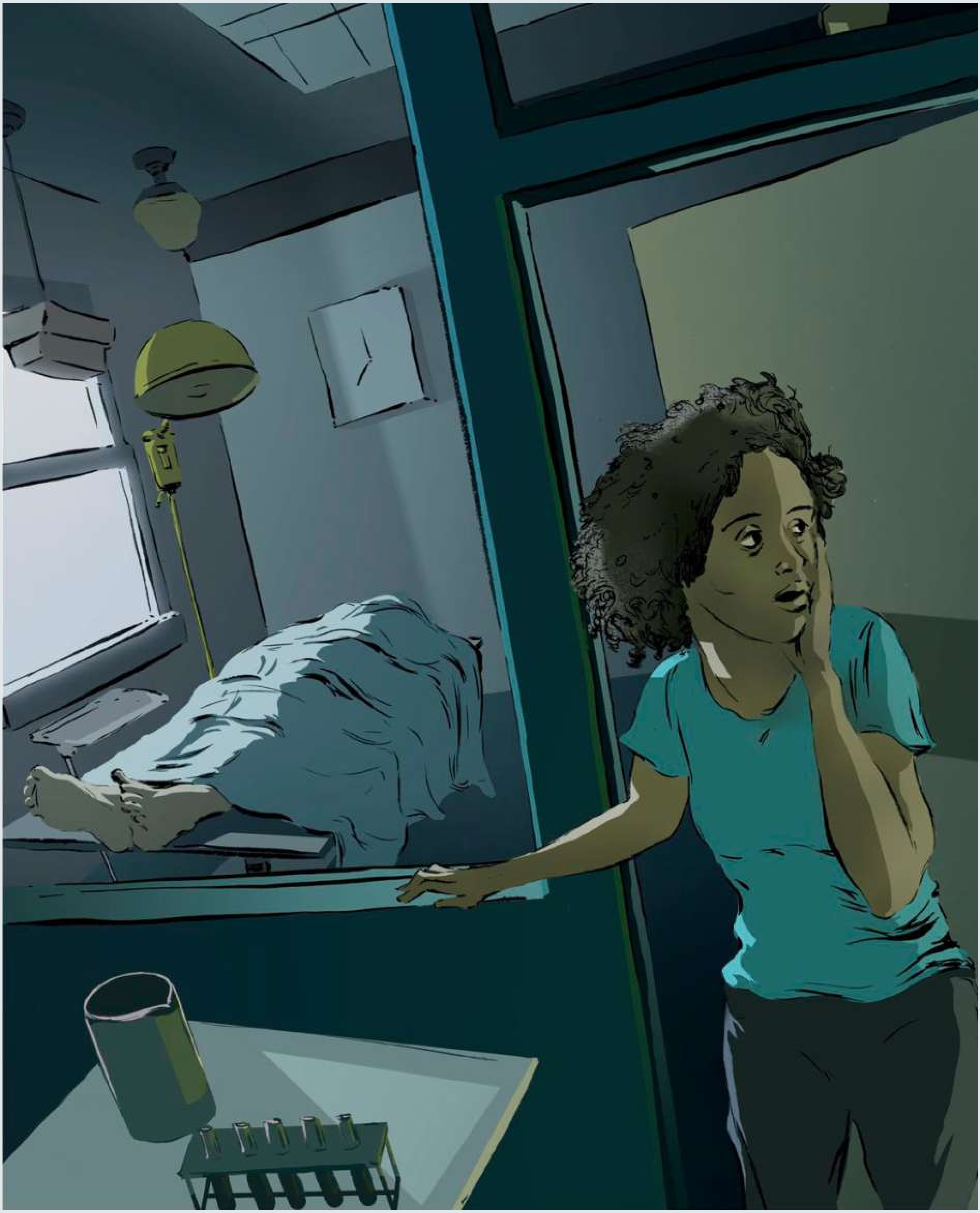
SARAH HAD BEEN STARING at computer screens for 20 hours straight and her vision was blurring. She stood up, her chair scraping along the floor.

"Finished for the day?" Lilar asked. He looked as red-eyed as she did.

"Going for a walk. I need to clear my head."

Outside it was dark and cold. Sarah thought about going back for a jacket but changed her mind. The cold would wake her up. It might help her squeeze another hour or two of work from the day.

She walked down the hill and into town. There weren't many lights on, and the streets were dark. The town



centre was soon behind her and she was passing one-storey brick bungalows and older, wooden homes. Most of the houses and gardens were well kept. No one was out on the street. Many of the homes were completely dark, but a few still had lights on, their windows glowing warm in the cold night air. The street lights themselves had been turned off. Maybe to encourage people to stay indoors, she thought. Moonlight made thin by cloud cover threw some relief across the street.

Something ran across the street in front of Sarah and paused at the other side to glance at her. It was hard to be certain, but Sarah thought it was a small ginger cat, not much older than a kitten. It disappeared under a hedge. Another cat scarpered from the hedge and ran up the street until it was swallowed by darkness.

She stopped and listened. There were no sounds of dogs or owls or nightjars. To the left she could hear a television in one of the homes. A cat snarled behind her, and another cat replied with a loud hiss. She turned to see if she could find them, but without luck.

Sarah shivered. The cold was getting to her. She was halfway back to the hospital when she heard a caterwaul from somewhere in town.

"THERE'S A MOVE to break the town's isolation," Arad told her in the morning.

Sarah had stumbled into the kitchen, yawning and stretching. She went to the window and peeked outside. The clouds from last night had banked up. The sky was grey as far as she could see. Nearby trees swayed with a strong wind. A cat pounced on to the window sill, startling her.

"It's going to rain," Sarah said, regaining her composure. She faced Arad, turning her back on the tabby. "Tom Prince, right?"

Arad nodded. "He is trying to convince the authorities that only the refugee camp needs to be quarantined. He's not keen on everyone having to give blood samples."

"Good white middle-class Anglo-Australians can't be responsible for any disease outbreak."

"I know Lilar is trying to explain the science to the Minister for Health, and maybe she can convince Prince to shut up and lie down." She shrugged. "You know, I think Prince understands the science, intellectually I mean, but I don't think it matters to him. As far as he's concerned, there is a principle at stake and he will not allow any amount of evidence to gainsay him."

> "WILLOUGHBY COULD BE THE VECTOR FOR A DISEASE THAT WILL KILL THOUSANDS … POSSIBLY TENS OF THOUSANDS."

Sarah heard a voice outside and looked through the window again. A tall woman with grey hair tied in a bun was walking determinedly up the hill. She was followed by two cats. Sarah peered through the glass. No, three cats. That was odd. The woman stopped with her hands on her hips as if catching her breath. The cats twined around her legs. Sarah could almost hear them meowing.

"Cats," she said under her breath, repressing a shiver.

"Locus for *T. gondii*," Arad said automatically, as if Sarah had asked her a question.

Sarah frowned. "I need to make a telephone call."

LILAR APPEARED WITH A WOMAN about Sarah's age. "Prince has won. The Minister's lifted the quarantine and stopped the blood sampling." He waved at the woman. "This is Dr Hunt, one of the two local GPs."

Dr Hunt moved forward to shake Sarah's hand. With the other hand she offered a foam icebox. "Your blood samples," she said. "At least, as many as I could gather. I know John Upward – he's the other GP in town – has some for you as well."

Sarah took the icebox and thanked her. Dr Hunt smiled and looked slightly apologetic. "Wish I could have done more." She shrugged. "I'm going to the refugee centre. I'll take samples there and bring them to you.

Shouldn't take more than a day or two."

Sarah thanked her again and asked: "The first local to show symptoms – Ava Gable, right? – was she your patient?"

Dr Hunt shook her head. "No, John's. But the next two locals to show symptoms were both mine."

"Did you have to treat them for anything before the onset of symptoms?"

"The usual thing this time of year, with all the pollen in the air. You probably already know hayfever's a real problem in rural areas."

"They both suffered hayfever before?"

"Yes, but this year it was more serious. More serious for a lot of people, in fact. Pollen count must be pretty high this season."

SARAH'S LEFT CHEEK MUSCLE contracted with a message from the microspan implant. It was from Cam MacInnes.

"Lab report sent to your account. Check partial genome sequence. It's the same for all the samples. Cf archive sample."

She logged into her university account and found the report. A series of codons flittered along the back of her iris.

Lilar appeared and noticed her out-of-focus stare. "You reading?"

She nodded absently.

"*T. gondii*?"

"Cam analysed the samples I sent him from our dead human and rodents. He compared them to the protozoan's sample DNA we have in our archive."

"And?"

"He found a mutation common to all the samples I sent."

"Unless someone's already found out what every codon in *T. gondii* transcribes to … "

"No."

" … it could take months to find out what the mutation does."

"Normally," Sarah agreed.

"Normally?"

Sarah focused on Lilar, breaking the link with her account. "I have an idea. Well, a hunch. Give me until this afternoon, and then I'll talk to you and Arad. In the meantime, you might try and get the quarantines put back in place."

"I think my influence with the Minister has run out of steam."

"You and Arad have confirmed that the human victims died from complications arising from an infection by *T. gondii*?"

"Yes. All except Ava Gable from encephalitis. She died from a heart attack."

She sighed heavily. "Suggest to her if my hunch works out, Willoughby could become the vector for a disease that will kill thousands in the next year. Possibly tens of thousands. And as a side-effect, completely devastate the nation's already battered ecosystem."

For a long moment Lilar said nothing, then copied Sarah's sigh. "Well, then. That might budge her. You'll talk to us this afternoon?"

"I promise."

SARAH SPENT THREE HOURS talking to every local she could find. She knocked on doors and visited most of the shops in the main street. On the climb back up the hill to the hospital she thought she was being followed. She stopped and turned around. No one was there. It was early afternoon and the place was as quiet as a dream. There were no birds. None. She was in the middle of the country and there wasn't a single cockatoo in a single tree. She looked up into a sky empty of all life. When she brought her gaze back to ground level she noticed the scrub to her left move. It was the largest cat she had ever seen.

A feral, she thought to herself. It had large paws and a curious, intelligent face with large yellow eyes that studied her intently. She resumed climbing the hill, but kept her gaze on the cat. It followed her for a while and then disappeared behind the tree line. It made no noise at all.

When she entered the annexe she went straight to the security desk. Paul and a different policeman were on duty.

"Hello Dr Amedi," Paul said. "I think it's going to rain today."

"Are you a local, Paul?"

"I moved here about 10 years ago, if that's what you mean."

"Do you live with your family?"

"Oh, no. I'm not married, Dr Amedi. I live by myself. I have a flat behind Mrs Tingwell's place. She's a widow, you know."

"Do you have any pets?"

"No. I've never had pets." Paul thought for a moment. "Although lately I've been thinking about getting one."

"A cat?"

Paul nodded, surprised. "That's right."

"And you?" Sarah asked, turning to the policeman. He was taken aback.

"Umm."

"Do you have a family?"

"Sure."

"And pets?"

"Now we do. The kids have all got cats. Don't know where they came from, but we seem to have a pride full."

Sarah nodded her thanks and went through to the lab. Lilar and Arad were already there.

"Did you talk to the Minister?" Sarah asked Lilar.

"She said she would consider it. I will phone her again if your hunch convinces me it's necessary."

"I'd lay odds it's no longer a hunch," Sarah said confidently.

"Really?" Arad asked, crossing her arms. "And why is that?"

SHE LOOKED UP INTO A SKY EMPTY OF EVERYTHING EXCEPT A FEATHERING CONTRAIL LEFT BY SOME HIGH-FLYING AIRCRAFT

"I've been talking to people."

"Talking?"

"Yes. We've been looking at medical records and tissue sampling. But not talking to anyone. At least, not in any systematic way."

"OK," Arad said warily. "Shoot. Give us your hunch."

Sarah took a seat. "We all know *T. gondii*'s preferred host is the cat. It is the only host where the parasite reproduces sexually."

"And Willoughby has an unusually large number of cats, yes," Arad said, intercepting her. "We know this."

"Serological studies suggest that toxoplasmosis may be the most successful parasite-caused disease in humans worldwide."

"But the fatality rate is very low," Arad pointed out. "And then almost always in the most vulnerable, like the unborn and the very young. Are you suggesting *T. gondii* has mutated to become more dangerous?"

"Yes, but not directly. There are strong links between *T. gondii* and changed behaviour in its hosts. It alters the behaviour of infected rats so they are more vulnerable to cats. There is anecdotal evidence it also affects the behaviour of some humans."

She turned to Arad. "You remember you told me that the first person to be infected who subsequently died was a woman who brought pets to the children at the refugee camp?"

Arad nodded. "Ava Gable."

"The pets were cats." Sarah made it a statement, not a question.

"Yes, I believe so."

"According to Dr Upward – her GP – she was asthmatic. Her reaction to cats was so strong she redlined every allergy test in the category. She was found dead in her house."

"A house full of cats?" Lilar ventured.

Sarah nodded. "Her windpipe was so restricted she had a heart attack trying to get enough air to breathe. And she was covered in a rash so severe the skin was cracked and weeping. Her last few days must have been a living hell, yet still she kept cats in her house."

ARAD TOOK SARAH BACK to the landing field for her lift back to the university.

"Tom Prince gave in. The quarantine is back in effect. Do you think it will be too late?"

Sarah shrugged. "We'll know soon enough."

As the tiltrotor lifted off, Sarah made sure to wave goodbye to Arad, but she was already heading back to the car.

Halfway back home, she had the sudden and overwhelming urge to buy a kitten.

"So the infection is contained?"

"I wouldn't say that. Political interference and populism got in the way of the science."

"So the infection isn't contained?"

"I wouldn't say that, either. We won't know for some time if the second quarantine was in place quickly enough. Weeks. Maybe months."

"How will we know?"

"Two things. Watch for a rise in the sale of cat food. And watch the morgues."

— Transcription from interview with Dr Sarah Amedi on WorldNetNews, 14 March

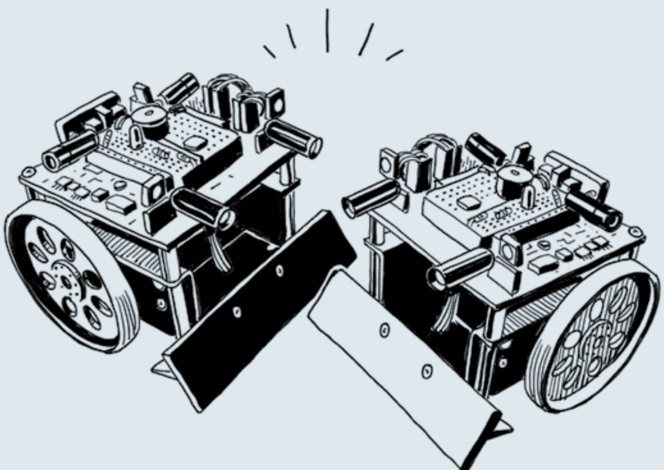
EDLYN TOKLEY is studying science at the ANU and spends a lot of her free time reading (especially manga) and writing. She has loved SF ever since her parents forced her to watch *Babylon 5* at the age of four.

SIMON BROWN has been writing SF for nearly 50 years and is still learning. His website can be found at simonbrown.co

GADGETS AND GIZMOS

Robotics in a kit

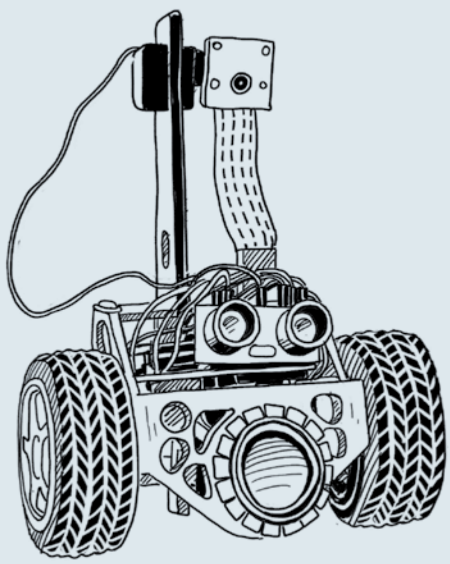
ROBOTICS IS COMPLEX and multi-disciplinary, combining engineering, construction, electronics and computer programming. It can be daunting to know where to start, but one of the best ways to learn about robotics is to be hands-on and build your own robot – and the easiest way to do that is with a kit. There are many on the market, from the sleek Lego range to the small but perfectly formed BOE-Bot. The selection listed here are all suitable for beginners but versatile enough to allow those with more experience to adapt and expand the robots' capabilities.



1

SUMO BOTS

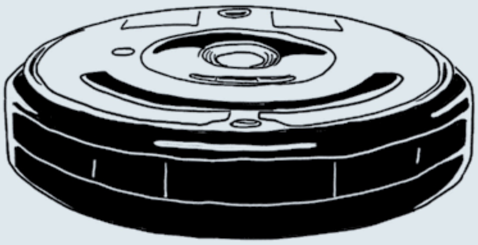
From Parallax, the SumoBot is designed to compete in the Sumo pits – one of the most popular robot trials where one robot tries to knock the other out of the ring sumo wrestling style. The SumoBot kit is one of the easiest and quickest ways to get into the game. The robot has a surface-mounted BASIC Stamp® 2 'brain', an array of infrared sensors as well as opponent-seeking navigation that employs programmed artificial intelligence.



2

PI-BOT

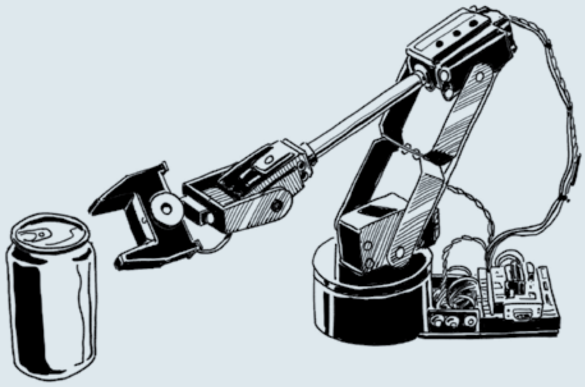
The Pi-Bot is an affordable, complete robot kit for building and programming. Controlled using the standardised Arduino C programming language, the robot can be used by students or engineers wanting to learn the hardware and software of robotics. Developers of the kit are working on new sensors and motors to provide more capabilities. The Pi-Bot gets its name from its unique chassis shape when viewed from above – the letter pi.



3

IROBOT CREATE 2

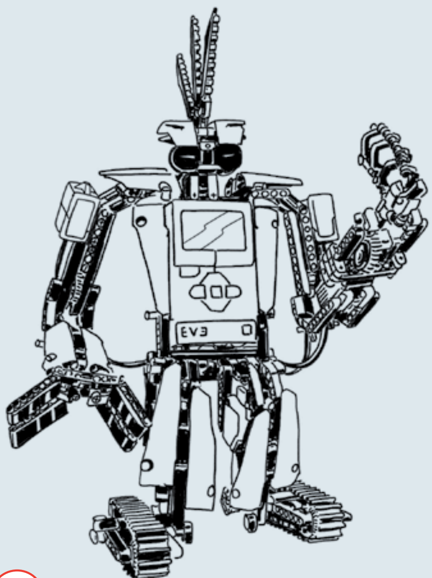
The Create series was introduced in 2007 based on iRobot's Roomba vacuum cleaning platform. By connecting your laptop or adding an onboard microcontroller you can program the robot with new behaviours, sounds and movements. You can also equip your robot with extra sensors, cameras and grippers.



4

LYNXMOTION ROBOTIC ARM

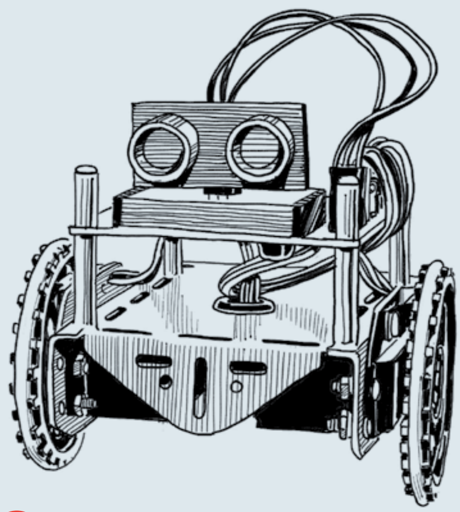
An affordable robotic series that comes in different specs for its hardware, control electronics and software. All arms have a rotating base, a shoulder joint that allows up-down movement in a single plane and elbow and wrist joints that add up to four DOF (degrees of freedom, a measure of 3D movement). Optional rotating joints add up to a total of six DOF.



5

EV3RSTORM

Lego's signature humanoid robot is a cool, if pricey option. It uses Lego's Mindstorms software, which can be downloaded from Lego's website. Being made of Lego blocks the robot can be assembled in five possible configurations, including a snake-bot, a forklift-like gripping robot and a ball-flinging robot. The EV3 microcontroller brick either uses a supplied program or allows you to follow the steps to create your own.



6

BOE-BOT

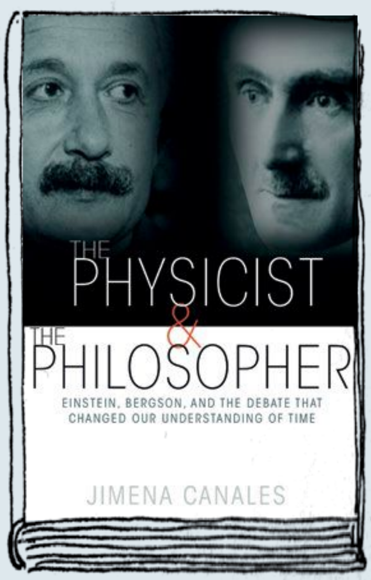
Short for Board of Education robot, BOE-Bot is widely used in robotics classes. It has a main circuit board, a plug-in BASIC Stamp microcontroller, two motors to drive the wheels, and an aluminum chassis the parts bolt on to. Students can use Erector set parts, Lego blocks and additional motors to build custom projects. It runs on four AA batteries and can be adjusted to walk on six legs, sense objects or pick up things with optional attachments from manufacturer Parallax.

— BILL CONDIE

ILLUSTRATIONS
Jeffrey Phillips

REVIEWS

Einstein's stake in changing time



NON-FICTION
The physicist and the philosopher: Einstein, Bergson, and the debate that changed our understanding of time
by JIMENA CANALES

Princeton University Press (2015)

IT IS NOW HARD TO IMAGINE a time when Albert Einstein was not a household name, but at the beginning of the 20th century there was an intellectual who was much better and more widely known – the French philosopher Henri Bergson.

While their positions in the public consciousness have gone through a reversal over the past 100 years, a debate on 6 April 1922 about the nature of time between the two men marks a milestone in the relationship between philosophy and science. The debate arguably set up the competing dual world view separating the humanities and science to this day. Or as author Jimena Canales has it, "splitting the century into two cultures and pitting scientists against humanists, expert knowledge against lay wisdom".

At a meeting of the French Society of Philosophy, Bergson, "one of the most respected philosophers of his era" stood up to complain about Einstein's theory of relativity, which he dismissed as "metaphysics grafted upon science".

Bergson was particularly concerned with how the theory dealt with the concept of absolute time. He argued science alone could not explain time adequately.

Bergson, whose earlier books included such titles as *Time and Free Will*, *Matter and Memory* and *Creative Evolution*, believed Einstein's theory ignored the "intuitive" aspects of time, which he said was part of the "vital impulse" of life and creative expression.

Einstein, unsurprisingly, could not disagree more. He found Bergson's ideas irreconcilable with physics and little more than soft, mystical mumbo jumbo.

The two men were diametrically opposed in nearly every aspect of their lives. As Canales explains, Bergson "gladly extolled the virtues of thinking about the world in terms of the shifting relations and criticised Einstein for producing a theory based on absolute concepts".

Canales' account of the explosive debate is a solid but rewarding read. She describes an age in which intellectual disagreement was settled through largely civil debate. Although each side was also capable of attempting to manipulate public perceptions of the other.

As Canales notes, Einstein "actively tried to forge" the notion that Bergson held science in disdain and "for having an irrational abhorrence for scientific facts". In fact, Bergson had carefully stated on more than one occasion that he would not go against the facts of observation. He wrote: "We take the formulas … term by term, and we find out to which concrete reality, to what thing perceived or perceptible, each term corresponds."

Canales does a good job of putting the debate in historical context, taking its place in a long history of philosophical inquiry into the nature of time from when Saint Augustine asked in his *Confessions*, "what, then is time?" to Benjamin Franklin who declared "time is money".

She has ordered the book in four main parts – the first concerning the meeting and debate itself, the second looking at the men and how Einstein's work continued to be viewed, at least in part, against Bergson's critique. The third section looks at "things" and the two men's disagreement over the meaning, use and importance of objects such as clocks, the telegraph, atoms and molecules. Finally Canales looks at the words the men used about the other. "By the end of their lives, Bergson reconsidered Einstein and Einstein reconsidered Bergson, but their views remained irreconcilable."

EINSTEIN FOUND BERGSON'S IDEAS IRRECONCILABLE WITH PHYSICS – SOFT, MYSTICAL MUMBO JUMBO.

Bergson drew first blood in the 1922 debate. What Bergson had to say is believed to have cost Einstein the Nobel that year for his best-known theory (it was awarded that year instead for his discovery of the law of photoelectric effect).

But as Canales notes, "for better or worse, the debate between Einstein and Bergson has still not ended, and possibly never will" and asks the question "was the theory of relativity science, philosophy or both?"

— BILL CONDIE

A relatively popular theory

IN CASE YOU HADN'T NOTICED it's been 100 years since Albert Einstein submitted the final version of his world-changing theory of general relativity to the Prussian Royal Academy.

In it, he described gravity as a function of the curvature of space and time by matter and energy – a concept with far-reaching consequences.

The theory could describe and explain the expansion of the Universe, the physics of black holes and the bending of light from distant stars in the now familiar phenomenon of gravitational lensing. It remains the basis for much of our understanding of the cosmos.

Unsurprisingly the publishing industry has responded to the anniversary with gusto. We have selected five of the best, which, while we didn't plan it that way, mostly come from Princeton University Press, as is fitting.

Einstein first visited Princeton in 1921, the year before he received the Nobel Prize. He gave a series of lectures on his work at the university, which he believed had done the best work on his theory. He renewed the relationship with the town of Princeton in 1933 when he took up a post at its Institute of Advanced Study, an affiliation that would last until his death in 1955.

While the IAS has no formal connection to the university the two have enjoyed close collaborative ties over the years, as described in *Einstein: A hundred years of relativity*. It is the most accessible of our collection, enhanced by wonderful pictures from sources including the Albert Einstein Archives and the Hebrew University of Jerusalem.

The book also examines Einstein's appeal to the public imagination – which is only partially explained by his groundbreaking theory. Andrew Robinson's main biographical narrative is enhanced by 12 essays by eminent scientists, scholars and artists that put Einstein's life and work in perspective.

For a meatier look at Einstein's work there is *The road to relativity*, a wonderful book that combines a facsimile of Einstein's original manuscript, an English translation and a rich annotation that is accessible, just about, to the enthusiastic non-mathematician.

Or you can turn to the great man himself and the re-issue of *Relativity*, Einstein's own attempt to introduce his theory to a lay audience. To be honest, we must judge his success in this with some ambivalence. It's a tough read by any standards, although one is struck by the charm of his language, even if the elegance of his mathematics is beyond our grasp.

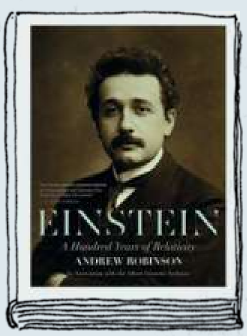
> EINSTEIN'S APPEAL TO THE PUBLIC IS ONLY PARTIALLY EXPLAINED BY HIS THEORY.

An Einstein encyclopedia is an invaluable companion to the serious Einstein researcher. A comprehensive collection of the theories, concepts, friends, collaborators and romantic interests in Einstein's life.

Finally, *The perfect theory* takes us beyond Einstein's life by placing his work in context and explaining the impact it has had over the years, and also its relevance to today's cutting edge inquiries.

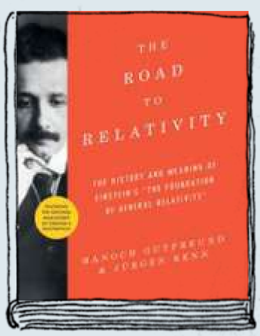
Astrophysicist Pedro G. Ferreira does a wonderful job at bringing the mathematics and science to life.

— BILL CONDIE



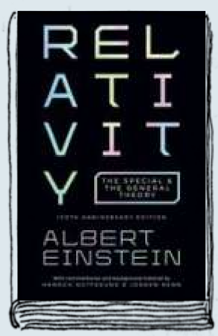
NON-FICTION
Einstein: A hundred years of relativity
by ANDREW ROBINSON

Princeton University Press (2015)



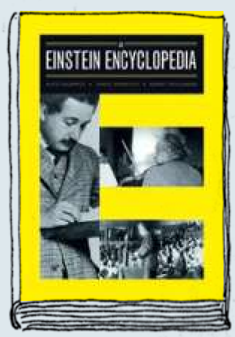
NON-FICTION
The road to relativity
by HANOCK GUTFREUND and JÜRGEN RENN

Princeton University Press (2015)



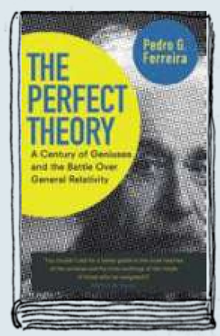
NON-FICTION
Relativity: The special & the general theory
100th anniversary edition
by ALBERT EINSTEIN

Princeton University Press (2015)



NON-FICTION
An Einstein encyclopedia
by ALICE CALAPRICE, DANIEL KENNFICK and ROBERT SCHULMANN

Princeton University Press (2015)



NON-FICTION
The perfect theory: A century of geniuses and the battle over general relativity
by PEDRO G. FERREIRA

Abacus (2015)

REVIEWS

NON-FICTION
Heartland
by the AUSTRALIAN CONSERVATION FOUNDATION

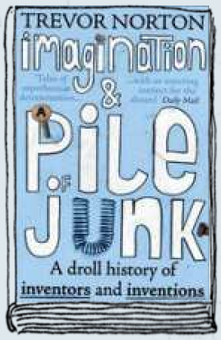
Echo (2015)

THIS BEAUTIFUL BOOK celebrates 50 years of the Australian Conservation Foundation through pictures of the remarkable island continent.

The original photography is by MAPgroup documentary photographers, a non-profit association of around 40 people ranging from emerging photographers to well-established award-winning professionals.

This work is a remarkable testament to the foundation's dedication to preserving natural beauty, but also acknowledges the human place within the natural landscape.

— BILL CONDIE



NON-FICTION

Imagination and a pile of junk: A droll history of inventors and inventions by TREVOR NORTON

Coronet (2015)

TREVOR NORTON IS A MARINE BIOLOGIST who has retired from the University of Liverpool to his home on the Isle of Man. Clearly in another life he would have liked to be an engineer or inventor. His fascination in the endless creativity of people is immense and his admiration clear.

"Modern man has been around for only 200,000 years or so in a Universe 13.7 billion years old and in that time he has achieved so much."

In this entertaining read, originally issued last year and republished for the first time in paperback, Norton rattles through an enormous number of inventions from the steam engine, to torpedo guidance systems, from lighthouses to longships, diving bells to dentures – his range is far and wide.

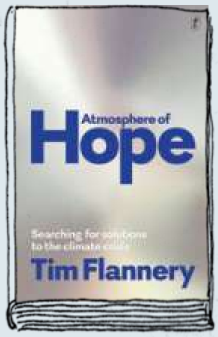
He has a keen eye for the absurd and points out that the more groundbreaking the invention, the more they are ridiculed initially. When presented with a device that allowed communications over vast distances, the Admiralty declared, "telegraphs of any kind are wholly unnecessary".

New technologies were also often quickly co-opted for cunning schemes. When smaller hand-held cameras became available, it became possible to take pictures of street scenes, including the plight of the poor in Victorian London. Irish philanthropist Thomas Barnado quickly saw the benefits of taking before and after pictures of his rescued children to drum up more support for his eponymous homes "but he wasn't above dirtying up the 'before' boy ... to increase the contrast with the spruced-up 'after' young gent ..."

This is all handled with a light touch, although from time to time "droll" drifts into "Dad joke" territory. Still, he more often hits than misses the mark and this rapid-fire little volume is packed full of interesting and obscure facts.

Who knew, for instance, that the world's first road traffic lights were installed near the Houses of Parliament in Westminster so members could cross safely? Or that Hollywood actress Hedy Lamarr knew how to stop radio waves being jammed?

— BILL CONDIE



NON-FICTION
Atmosphere of hope: Searching for solutions to the climate crisis
by TIM FLANNERY

Text Publishing (2015)

HOPE DOESN'T OFTEN get a look-in during the debate on climate change. The data of rising temperatures, acidification of the oceans and changing rainfall patterns are more usually associated with gloom as is the apparent inability of governments to act on these concerns. Meanwhile, the rancorous chorus of scepticism and denial make any hope of a solution seem remote indeed.

But into this debate, 10 years after the publication of his international bestseller *The Weather Makers*, steps Tim Flannery with a message of genuine optimism, as he outlines the exciting technologies and approaches to dealing with climate change that are already available or soon may be.

He looks at the means to reduce the carbon in the atmosphere directly by changing the energy components we use. He assesses the uncertain future for the oil, gas and coal industries, which have experienced massive changes over the past decade, and, he suggests, face further sharp declines. He looks at alternatives such as solar and wind. Chanelling Elon Musk he reminds us that the Sun radiates more energy in a few hours than the planet uses in a year, and like Musk says the future depends on efficient batteries.

He discusses the pros and cons of nuclear power and radical geoengineering solutions, such as pumping sulfur into the atmosphere to reflect sunlight. He describes these schemes, with their potential to go horribly wrong, as fighting poison with poison.

The most exciting technologies, Flannery says, are those he describes as "third way" solutions – neither emission reduction plans nor geoengineering mega projects. Instead these third way projects work with the Earth to enhance and restore natural processes that balance greenhouse gasses – "processes that are as old as life itself".

They include the various means of atmospheric carbon capture – seaweed farming, CO_2 snow production in Antarctica, the absorption of CO_2 by the "enhanced weathering" of silicate rocks and the manufacture of carbon-rich biochar and its use in reafforestation projects.

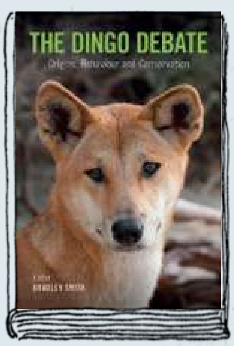
He also considers less radical engineering solutions such as painting cities white to reflect the Sun's rays.

But, writes Flannery, the greatest technologies might still be ahead of us as the challenges of dealing with climate change engage and define generations of thinkers, scientists and engineers.

"It is possible the next generation will astonish us with the solutions that we discover to safeguard our planet for our grandchildren and their grandchildren," he writes.

Time is running out, but a catastrophe is not inevitable.

— BILL CONDIE



NON-FICTION
The dingo debate: origins, behaviour and conservation
edited by BRADLEY SMITH

CSIRO Publishing (2015)

ANYONE FAMILIAR WITH THE DINGO and who has also watched the yellow street dogs common across Asia may well believe they have seen the dingo's closest relation. But Bradley Smith wants you to understand that dingoes are different.

In this exhaustive review of current scholarship on the Australian native dog he goes to lengths – the lay reader may think too many – to establish that the modern Asian dog, while similar in looks to the dingo, is firmly in the domestic dog species, *Canis familiaris*. By contrast the dingo, which did have its origins in a Southeast Asian wild dog, belongs with the wolves, coyotes and other wild canids in *Canis lupus*. There is still some argument about the exact taxonomy, but Bradley sets the stage for his close study of this beautiful animal, classification *Canis dingo*. It is a unique dog that, while not originating in Australia, is now very much a native.

And while his analysis may be exhaustive, he has good reason to make it, as the classification is crucial to much of the debate about these animals.

While undoubtedly a wild dog, the dingo has been shaped by its interactions with human societies. It now holds a rather precarious position in modern Australia where it is at risk from habitat destruction, persecution and cross-breeding with domestic dogs, the last arguably the most acute threat.

The debate in question, while having many facets, is at heart about whether the dingo can live alongside us. (The chapter on dingoes as pets is fascinating. It is, apparently a rewarding experience, but not for the part-time owner. You are either part of the pack, or you are not!)

The big question is whether the dingo has a future. Long the bête noir of farmers, are these dogs incompatible with agriculture? Or should we encourage their reintroduction in areas where they have been eradicated to introduce a vital, near-native, apex predator to control the other introduced pests that are ravaging Australia's indigenous species?

— BILL CONDIE

Monkey see, monkey do

DOCUMENTARY
Monkeys revealed

BBC EARTH (2015)
Run time: 148 mins

IT'S TIME TO MEET THE FAMILY in this, the latest in the BBC Earth series. And what a strange and large family are the apes, monkeys and lemurs that make up the primates.

With the customary BBC natural history unit production values, this three-episode series begins by introducing us to some of the 400 bizarre and colourful animals that make up the order. All share the big brains, binocular vision and opposable thumbs that make us us.

And they are quite a bunch – from imposing great apes like the orangutan, which has learnt to imitate the humans it meets, to the tennis ball-sized tarsier – a fearsome predator with almost supernatural powers. Its hearing is ultrasonic and its eyes, so large they cannot move in their sockets, are focused by the animal turning its head through nearly 360 degrees.

Then there's the tiny lemur, the Aye Aye, more ET than primate, so strange are its hunting skills. It taps branches to create a sort of sonar to find grubs, which it then captures with a specially adapted hypersensitive, long, skinny feeding finger.

The next two episodes take a closer look at two of the primates' unique characteristics – their love of family and their intelligence. There's the physical contact and play that is vital to their survival and the highly developed social status that has developed in almost every group of primates.

But it is the massive ability to learn – and pass on that learning that really sets this order apart. These family traits, a settled way of doing things among a certain group of primates that differs from the way another group may behave, can only be described as the beginnings of culture. It was something that until recently we humans thought we had all on our own.

— BILL CONDIE

IMAGE
Roadshow Entertainment

TOP 5

Bestsellers

1

The Wright brothers
by DAVID McCULLOUGH

Simon & Schuster (2015)
RRP $32.99

2

Being mortal: Illness, medicine and what matters in the end
by ATUL GAWANDE

Profile Books (2014)
RRP $22.99

3

Elon Musk: Tesla, SpaceX, and the quest for a fantastic future
by ASHLEE VANCE

Ecco / HarperCollins (2015)
RRP $28.99

4

The immortal life of Henrietta Lacks
by REBECCA SKLOOT

Macmillan (2010)
RRP $34.99

5

Thinking, fast and slow
by DANIEL KAHNEMAN

Penguin (2012)
RRP $22.95

— FROM THE NEW YORK TIMES SCIENCE BESTSELLER LIST

PAUL DAVIES is a theoretical physicist, cosmologist, astrobiologist and best-selling author.

Abacus

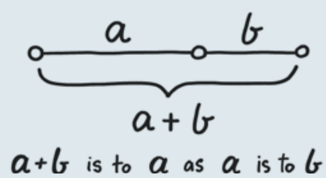
Fascinated by a perfect figure

The golden ratio has long been associated with beauty in art and nature.

SOME NUMBERS ARE HELD to be lucky, others unlucky and yet others are imbued with divine or mystical significance.

One, however, is associated with beauty. Known as the golden ratio, its repeat appearance in architecture, design, nature and the proportions of the human body has long been a source of fascination to mathematicians and artists alike.

In mathematics, two numbers are said to be in a golden ratio if the ratio of the larger (a) to the smaller (b) is the same as the ratio of their sum (a +b) to the larger number (a). That is, $(a + b)/a = a/b$. Expressed diagrammatically, it looks like this:



The value of the golden ratio is $\frac{1}{2}(1 + \sqrt{5})$, an irrational number: 1.6180889887 …

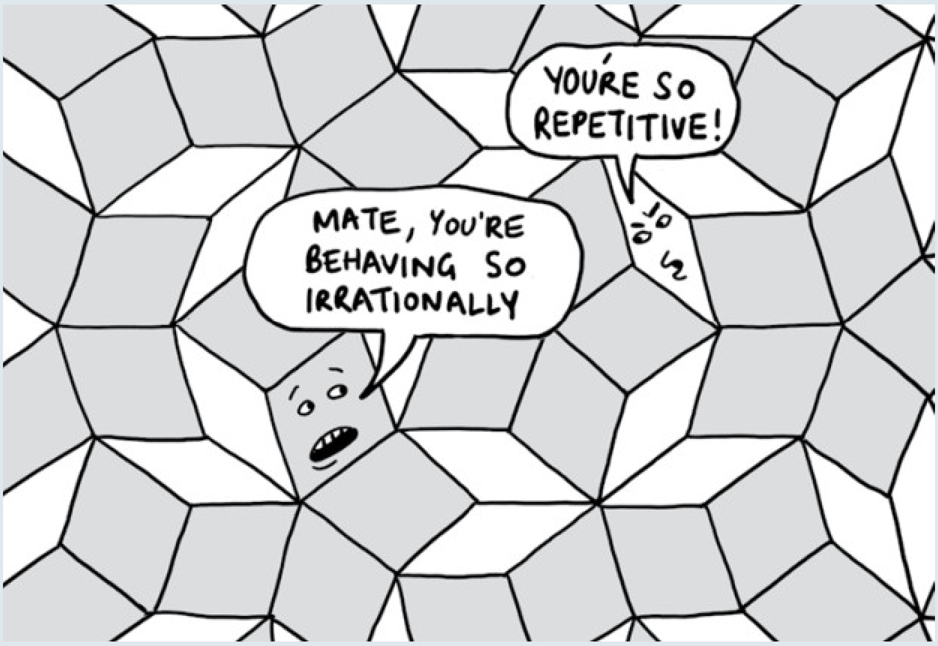
The Greek sculptor Phidias is said to have made use of the golden ratio in his design of sculptures in the Parthenon (none of which survive, unfortunately) and the first letter of his name, the Greek letter phi – φ – is used as the symbol for the ratio.

Leonardo Da Vinci used the golden ratio in his illustrations of geometric figures in Lucia Pacioli's manuscript *De Divina Proportione* (On the Divine Proportion), an influential treatise on architecture and the human body. The golden ratio is also evident in early Islamic architecture and in Gothic cathedrals such as Notre Dame in Paris and Chartres. Many books produced between 1550 and 1770 use this exact proportion.

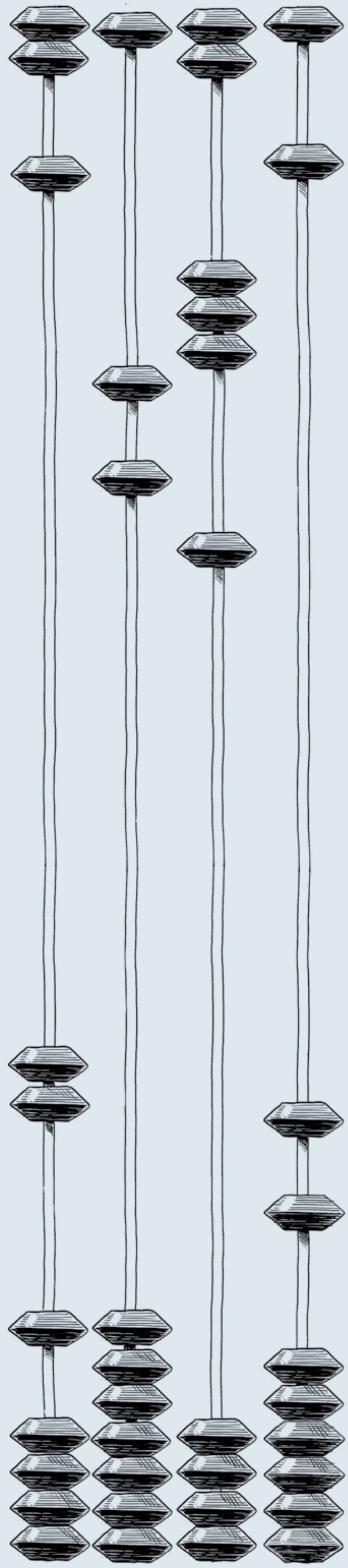
Today, the golden ratio crops up in contemporary tessellation patterns. Any floor tiler will tell you they can use triangles, squares and hexagons to create a pattern with a three, four or six-fold symmetry. What about five-fold symmetry? It is impossible to tessellate a plane using pentagons, but in the 1970s the Oxford mathematician Roger Penrose proved that a perfect tessellation pattern with five-fold symmetry could be created using a combination of two tiles shaped like a fat and a thin rhombus.

The ratio of the sides to the long diagonal of the fat rhombus turns out to be – you've guessed it – the golden ratio, φ. While for the thin rhombus, the ratio of the sides to the short diagonal is 1/φ. The Penrose tiling pattern appears in jigsaws, textbooks and, fittingly, on the patio of the Mathematical Institute at Oxford University. Some years after Penrose published his unusual pattern, scientists were astonished to discover crystals displaying a five-fold symmetry, previously thought impossible (they are known as quasi-crystals because they do not have a periodically repeating structure).

I have a curious personal association with φ. Forty years ago Stephen Hawking announced that black holes are not black but glow with heat radiation. We are familiar with hot bodies that cool down as they emit heat (think of your abandoned coffee going cold). Black holes do the opposite – they get hotter. In technical language black holes are said to have a negative specific heat. This means a black hole is unstable: the more it radiates, the hotter it gets and the faster it emits heat. This runaway process results in the black



Floor tiles have difficulty adapting to a five-fold symmetry. ILLUSTRATIONS: JEFFREY PHILLIPS

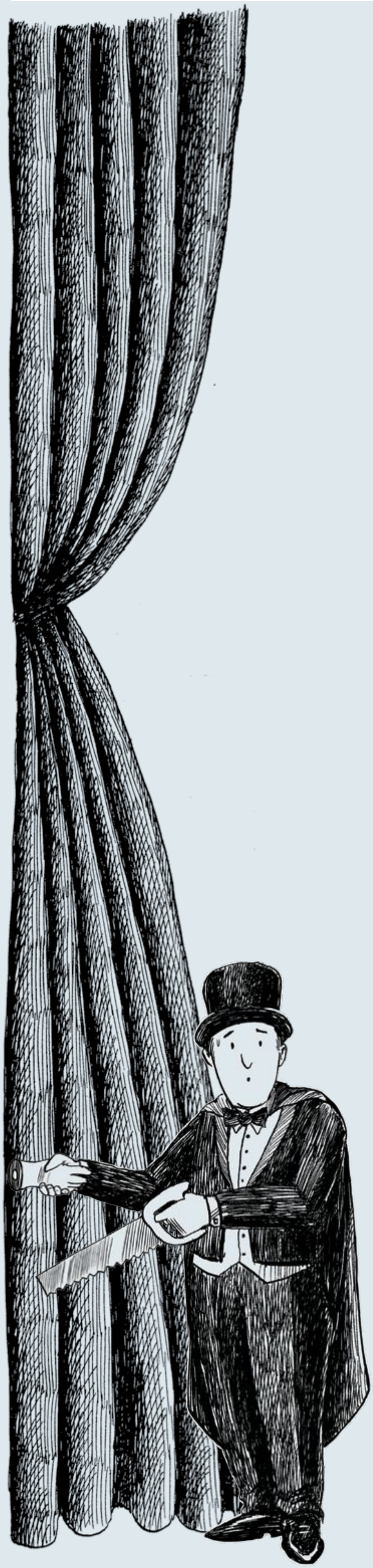


hole evaporating at an escalating rate before disappearing in an explosion.

I was at the lecture in which Hawking announced this astonishing result, and for a while I found it hard to believe. I began to take a close interest in the thermodynamic properties of black holes. I used a mathematical model to see how things might change if the black hole is spinning. To my surprise, I found that when the black hole spins fast enough, its specific heat is positive; that is, it cools as it radiates heat – like that cup of coffee. Now I should explain that there is a maximum spin rate for a black hole of a given mass, above which it would cease to be a black hole and turn into a so-called naked singularity – something that many physicists believe is impossible. Intriguingly, the flip-over between negative and positive specific heat occurs when the square of the spin rate reaches $1/\varphi$ of the maximum.

I discovered this peculiar fact in 1979 and still don't know what to make of it. As far as can be seen, there is no dramatic alteration to the structure or shape of the black hole at the transition point. Perhaps there is something in the warped architecture of the black hole that picks out φ, just as Phidias reputedly did with his Parthenon sculptures. Or perhaps the golden ratio is more deeply embedded in the structure of nature and this is one glimpse of it.

Whatever the case, this example – and others that have fascinated mathematicians and artists for centuries – illustrates that what is significant in nature is also likely to be beautiful.



JASON ENGLAND is a magician based in Las Vegas and a renowned authority on casino gambling and card handling.

Smoke & Mirrors

A poser for map makers with crayons

Mathematicians have struggled with a deceptively simple problem for decades.

ON A RECENT BREAKFAST OUTING my five year old niece was handed an intricately designed paper place mat and four crayons to colour in the pattern.

"I think I'm going to need more colours," she said. I know better than to argue with a five year old before 9 am and requested supplements. While she scribbled away with the extra crayons, I thought about Francis Guthrie.

In 1852, Francis wrote a letter to his brother Frederick containing a simple question about colouring maps. Francis had discovered he needed only four colours to colour a map of all of the counties in England so that no two adjacent counties shared the same colour.

He asked his brother if he thought England was unique, or if the rule could apply to every map.

It was a seemingly simple question: in fact Francis was asking for a formal mathematical proof that remains unsolved by any human hand to this day.

Upon receiving the letter from his brother, Frederick asked one of the foremost mathematicians and logicians of the day, Augustus De Morgan, for help.

De Morgan determined that certain simplified maps did not require more than four colours, but he was unable to demonstrate that this applied to all maps.

The problem essentially languished unsolved for decades. Then at last in 1879 it looked like the problem was cracked. Alfred Kempe, a mathematician and barrister who went on to become president of the London Mathematical Society, published a proof.

Kempe's proof stood for more than a decade, but could not stand interrogation by Percy Heawood, a mathematician who devoted nearly his entire life to the four-colour problem.

Heawood discovered a flaw in Kempe's analysis and alas, the four-colour problem arose once more.

Although Heawood was able to disprove Kempe's theorem, he could not find a new proof for the four-colour problem either. He *was* able to prove a five-colour theorem. But the quest for four did not die.

In the 1920s Philip Franklin narrowed the problem to maps containing 25 or fewer regions and was able to prove that no more than four colours are required.

Like Kempe before him, Franklin's work depended on reducing certain sections of the map that could easily be filled in using only *three* colours.

If the map that remained after removing this three-colour section could be filled in with four colours, then the original map could also be filled in with four colours.

But it remained to be seen if *all* configurations could be so reduced.

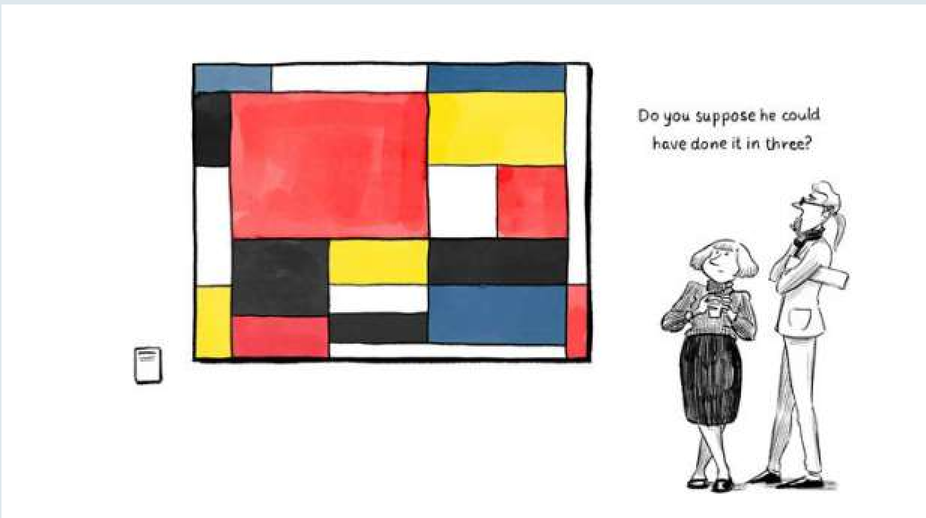
It would take another 50 years to get the answer.

In 1976, Kenneth Appel and Wolfgang Haken developed a complete set of all possible irreducible configurations for the four-colour problem.

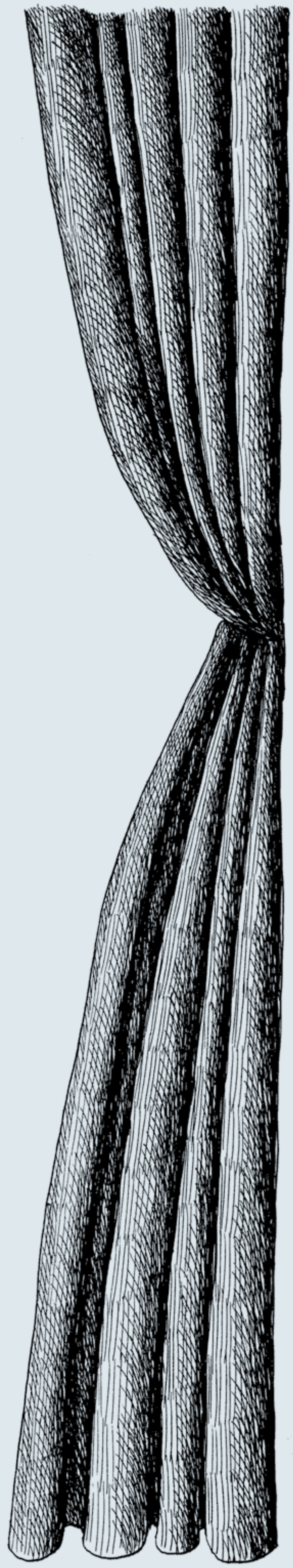
These configurations can be thought of as the basic building blocks of every possible map that can be drawn on a two-dimensional surface.

If each one of these configurations could be checked to ensure that they could be filled with only four colours, then the theorem would be proved.

The only problem? There were almost 2,000 irreducible configurations and



Gallery visitors pose a hypothetical for Mondrian. ILLUSTRATIONS: JEFFREY PHILLIPS



checking them all by hand was impossible – for a human. Enter the computer.

Over almost two months, Appel and Haken eliminated configurations from the list with a computer.

Eventually, after approximately 1,200 hours of non-stop computing, the job was complete and the four-colour theorem was proved at last.

They published their work in a book-length paper entitled *Every Planar Map is Four Colourable*.

At the time many mathematicians rejoiced at their ingenuity in using a computer to prove a mathematical theorem.

But not everyone was impressed.

Although their results were not directly refuted per se, Appel and Haken's proof was – and in some sense continues to be – controversial.

Many mathematicians consider such "brute force" attacks inelegant and unworthy of being called proofs. Appel and Haken themselves are even on record in a 1977 interview stating they knew of no proofs (including their own) that were "elegant and concise".

Or course, tasking computers with the "heavy lifting" has gained wider acceptance in the intervening decades. Today, computers are considered indispensable in many areas of mathematics research.

There have even been refinements to the four-colour theorem. But in the nearly 40 years since Appel and Haken's work was first published their basic approach of using specialised software to check and eliminate every possible "map" is still being used.

In the meantime an elegant and concise solution to the four-colour problem is still up for grabs.

Maybe my niece, with her paper and crayons, will crack it.

WHY IS IT SO?

WHY DO WE SWEAR?

Bad words cannot hurt us goes the old saying – and sometimes they can be benefical, writes KARL KRUSZELNICKI.

01
Swearing is a powerful act that can relieve pain.

SWEAR WORDS, OR BAD LANGUAGE, make up about 0.6% of our spoken language. Given that we speak an average of about 16,000 words each day, this means that about 95 of our daily words are profanities. In general, swear words are intended to be offensive – but in one situation they can be helpful.

BAD WORDS 101

Perhaps we swear precisely because we are told not to?

The word profane comes from the Latin roots *pro* meaning before and *fanum* meaning temple. So a profanity was something that you said only before the temple – or, in today's language, outside it. A profanity was definitely not to be spoken inside the temple. →

→ Cursing is universal. Profanities exist in every language, dialect or patois ever studied. They all have forbidden or bad words – regardless of whether that language is living or dead, is spoken by billions or a small tribe.

Interestingly, some cultures draw their swear words from religion. For example, when Shakespeare wrote zounds or 'sblood four centuries ago, he was using offensive (for the day) contractions of the phrases "God's wounds" (zounds), and "God's blood" ('sblood). Other societies fiercely protect the concept of the honour and "purity" of women. So, many of their swear words relate either to female genitalia, or to the theme "son of a whore".

POWER WORDS

Swear words have power and can change the human body. Merely hearing profanities will alter the electrical conductance of your skin, quicken your pulse, make the hairs on your arms rise and your breathing more shallow.

The power of swear words can change over time as our language evolves. For instance nobody today would be bothered by the word golly, which originally was an obscene and profane contraction of the phrase "God's body". And sometimes words once considered neutral can become a little unpleasant or uncomfortable to use. For example, the word coffin originally meant a box. But once the word coffin became linked to the concept of death, people stopped saying "Let's think outside the coffin", or "Let's see if there's anything to eat in the bread coffin". I think that's a gosh darn shame.

SET UP THE STUDY

Back in 2009, Richard Stephens and colleagues from Keele University in the UK looked at the link between swearing and pain. Many people swear when they suffer an injury and suddenly feel pain. The scientists asked: does the swearing relieve the pain, make the pain worse, or have no effect on the pain?

Sixty-seven unfortunate undergraduate students endured the cold pressor test which involved submerging their unclenched and non-dominant hand into cold water (5°C), for as long as they could stand it.

While their hand was in the cold water the students were instructed to say, over and over, either a swear word or a neutral (control) word. The swear words were chosen by asking the students for "five words you might use after hitting yourself on the thumb with a hammer". The experimenters chose the first swear word on each person's list to be their naughty word.

Why have a control word? The experimenters needed to control for the possibility that simply saying any word could change how long the subjects would be able to keep their hand in cold water. So they also asked the students for five words to describe a table – for example, bench, counter, desk, worktable, horizontal surface and so on. One of those words became the control word.

RESULTS – TIME AND HEART RATE

The study showed that while repeating the control word, men on average could withstand the cold water for 146 seconds, but women could go for 83 seconds.

If they repeated their chosen profanity, each gender could keep their hand in the cold water for an extra 40 seconds on average. A similar pattern was found for the heart rate.

Comparing men and women, in each case the men had a lower heart rate before the cold pressor test, with the cold pressor test and the control word, and with the cold pressor test and the swear word.

The pulse of both sexes was lowest before the cold pressor test. It rose slightly when they had their hand in cold water and were saying a neutral word, but rose even higher when they were saying their preferred profanity. The increase in the heart rate was approximately the same for each sex. This was

02
Swear jars are universally profitable because every language group swears.

probably related to the release of adrenaline – but no blood samples were taken to test these levels.

So, according to this study, swearing makes pain "go away" or become more "bearable" – because the subjects could keep their hand in cold water for longer.

THE POWER TO CHANGE PAIN

For better or worse, swear words are more common nowadays than in the recent past. After all, we use swear words to express surprise and happiness, or anger and disgust.

But what about people who tend to swear more than average? Does the power of profanity fade the more you use it?

In 2011, Stephens did a follow-up to see "if overuse of swearing in everyday situations lessens its effectiveness as a short-term intervention to reduce pain". The answer was yes. The more the subjects swore on a daily basis, the less extra time they could withstand cold water while swearing.

So if you're prone to cuss and curse, you would get less pain relief by swearing.

Here is the lesson for the day: it's OK to be profane, but only when you're in pain.

KARL KRUSZELNICKI is an author and science commentator on Australian radio and television.

CREDIT: Edited extract from *House of Karls*, Macmillan 2014

IMAGES
01 Jessica Peterson / JPM / Getty Images
02 Hidesy / Getty Images

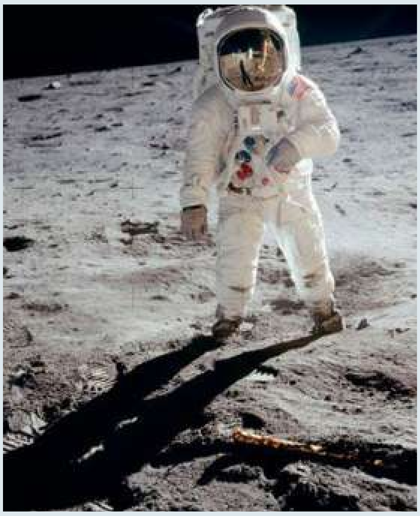
ILLUSTRATIONS
Jeffrey Phillips

EVENT

An Evening With Buzz Aldrin: Mission to Mars

Friday 27 November, Sydney State Theatre
Sunday 29 November, Melbourne Town Hall

Buzz Aldrin is an extraordinary man who has led an extraordinary life. He is one of only 12 humans to set foot on the Moon. Now he is talking about the possibility of travelling to Mars. Following the release of his book, *Mission to Mars*, Aldrin will be visiting Sydney and Melbourne to talk about the history of space exploration, a future beyond Earth and his plan to land humans on Mars by 2035. The event includes tales of Aldrin's adventures and dazzling images and footage from his personal library – it promises to be out of this world.

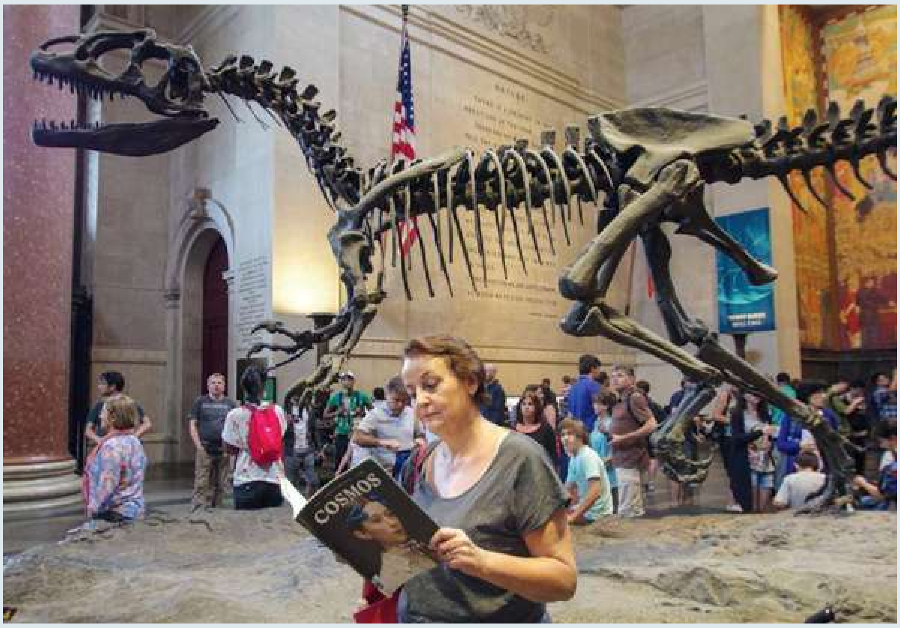


Cosmos Magazine is a proud partner with Live on Stage Australia for this event. Tickets are now on sale at Ticketmaster Australia.

→ bit.ly/BuzzAldrinEvent

IMAGE
Buzz Aldrin Enterprises

WHERE IN THE COSMOS?



Krystyn Hendrickson, on holiday in New York with husband Peter, catches up on *Cosmos* Magazine at the American Museum of Natural History in New York. With exhibits covering dinosaurs to outer space and everything in between, this huge museum is an essential item on any tour of New York.

MIND GAMES

Quiz

Q1. Pluto will reach its furthest point from the Sun?

Q2. True or false: Darwin strongly believed that the eye's complexity could have formed by natural selection.

Q3. Darwin wrote in *The Origin of Species* that the eye must have evolved in little steps from?

Q4. The place where the oldest stone tools, made 3.3 million years ago, have been found?

Q5. Lucy was a part of which ape-like species?

Q6. Name some corrosives that can react with the steel inside concrete.

Q7. How long can the spores in "bio-concrete" lie dormant?

Q8. The ancient pioneering stars that astronomers believed they have finally seen in a galaxy 12.9 billion years old.

Q9. This telescope was used to conduct the largest survey of the ancient Universe ever attempted.

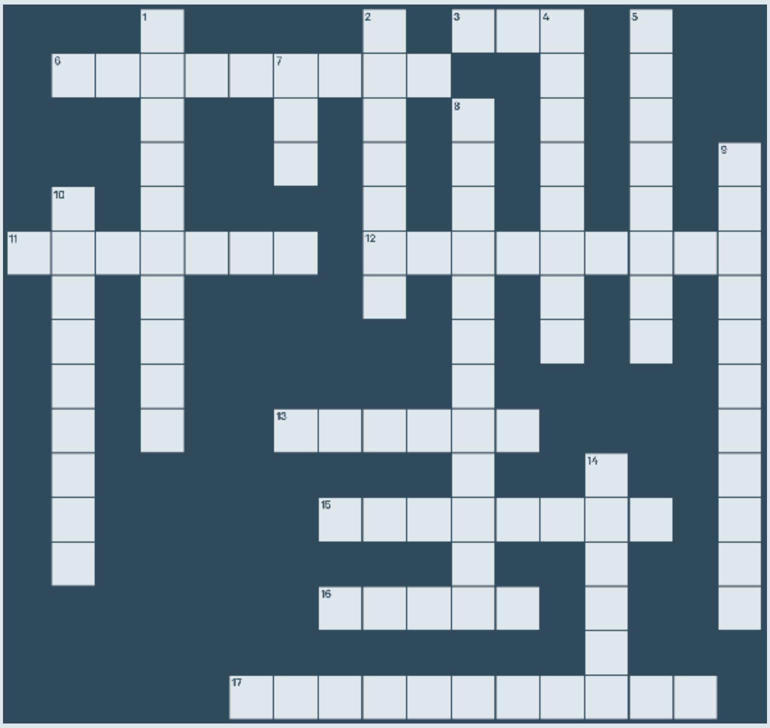
Q10. The body's waste disposal system is a web of drainage channels called?

Q11. What are the two major pipework systems running through your body?

Q12. Describe the new method used to dissect the mouse meninges, which led to the discovery of the brain's lymphatic drain.

Answers will be published in issue 66

Cosmos crossword



Answers will be published in issue 66

ACROSS

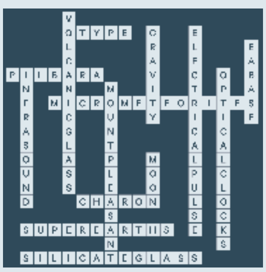
3. Pluto's heart is?
6. Pluto has mountains as tall as New Zealand's ... (5,4)
11. Eddington's term for quantum systems.
12. Organism looks like a floating eyeball.
13. Animal known to use stone tools?
15. Lymphatic vessels in the brain were discovered in ...
16. See clue: 10 down.
17. *Homo habilus* translates to ... (3,8)

DOWN

1. The Russian searching for intelligent alien life in the Universe. (4,6)
2. These tools are 700,000 years older than the Oldowan stone tools.
4. Some single-celled creatures can detect light using these pigmented structures.
5. Concrete is too ... for most bacteria.
7. The name of the galaxy, three times brighter than others from its epoch, where ancient stars were found.
8. The name of an organism that thrives in inhospitable places.
9. Scientists speculated Pluto's haze is made of ... droplets.
10. Photons sometimes behave like?
14. About 1,000 of these atoms were collected for a time experiment.

SOLUTIONS: COSMOS 64

CROSSWORD



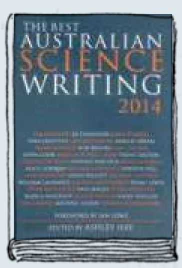
QUIZ

1. A phosphorus atom entombed in a silicon crystal
2. The Large Hadron Collider
3. Carbon
4. They trigger the immune response
5. Cosmic background radiation
6. United States National Radio Quiet Zone
7. 15 billion years
8. Eris, Makemake, Haumea and Sedna
9. Planetoids whose orbits carry them at least five times farther out than Neptune
10. Less than 20 hertz
11. Elephants, whales and crocodiles
12. Laser-Raman spectroscopy

WHERE IN THE COSMOS?

Send a photo of yourself reading a copy of *Cosmos* Magazine in an interesting place to competitions@cosmosmagazine.com.

Tell us your name, the names of others in your picture, your address, what you're doing and why you're there. Each published entrant will receive *The Best Australian Science Writing 2014*, published by New South Books.



WINNERS

Winners of the Apple Watch Subscribe and Win promotion were drawn on 6 August 2015. They are Paul Greatrex, Lakelands, NSW; Roger Grace, Moorabbin, VIC; and Lee Fontanini, Manjimup, WA. Congratulations to our three winners.

PORTRAIT

Will Feeney, field biologist

SNAKE CATCHER, bass guitarist, Arnhem Land tour guide – Will Feeney's CV has some eclectic early entries. But Feeney has now settled on science and is beginning to hit his stride as a field biologist.

"I'm interested in seeing what wild animals do," Feeney says, "then asking 'why are they doing that?'" He is back in his native Queensland after a stint at the University of Cambridge.

One of his recent studies was on African cuckoo finches in Zambia. Like all cuckoos they lay their eggs in the nests of other birds, leaving the others to rear their young. In this case the hapless parents are small songbirds called prinias. Although they do their best to drive the cuckoo finches away from their nests, the cuckoos have evolved crafty ways to sneak in.

For instance, while looking through old specimens, Feeney noticed the cuckoo finch had evolved to resemble innocent weaver birds. But prinias were not fooled for long. They are now aggressive towards any weaver look-alikes.

Feeney writes about his research for magazines and science news websites. "Doing science is like making music," he says. "It's important to do it well, but it's also important that other people get the chance to appreciate it."

— BELINDA SMITH

IMAGE
Richard Whitfield

ANTARCTICA
BY AIR
The world's most unique scenic flight


Rock star.
Leading a NASA mission to Mars makes QUT alumnus Dr Abigail Allwood a very big name on the world scientific stage. Her journey began with studying Earth Sciences, which led to a PhD and the discovery of some of the oldest evidence of life on earth in Western Australia.
Now based in California, Abigail's in charge of the 'Planetary Instrument X-ray Lithochemistry', or PIXL, at NASA's Jet Propulsion Laboratory. This instrument will use X-rays to study the chemistry of rock samples collected on the Mars 2020 mission. When you study science, technology, engineering or maths at QUT, the sky's not the limit, it's just the beginning.
QUT
a university for the real world®
bcm:qust0108 CRICOS No. 00213J